



Landfills as Bioreactors: Research at the Outer Loop Landfill, Louisville, Kentucky

First Interim Report

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By

Gary Hater and Roger Green
Waste Management, Inc.
BioSites Program
Cincinnati, Ohio 45211

Gregory Vogt
SCS Engineers
Reston, Virginia 20190

Wendy Davis-Hoover¹, David Carson¹, Susan Thorneloe² and Fran Kremer¹
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268¹ and Research Triangle Park, North Carolina 27711²

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U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

DISCLAIMER

Certain data presented in this Interim Report did not meet the stated quality assurance objectives. While these data are presented without flags in the body of the report, the reader is directed to **Appendix C - Data Validation Reports** which specifically identifies the parameters and data sets where certain objectives were not met. The Final Report for this project will include a data validation section and accordingly, data points of questionable quality will be flagged in that report at the conclusion of the project.

FOREWORD

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Hugh W. McKinnon, Director
National Risk Management Research Laboratory

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SECTION 1

EXECUTIVE SUMMARY

This Interim Report is presented to summarize data collected as part of a multi-year cooperative research and development agreement (CRADA) between the U.S. Environmental Protection Agency (EPA) and Waste Management, Inc. (WMI), examining two techniques of landfill bioreactor construction and operation. The project is underway at the Outer Loop Landfill located in Louisville, Kentucky, operated by WMI. Data presented here follow a quality assurance project plan (QAPP) established by the researchers prior to commencement of the project. The QAPP, appended herein, contains testing parameters, prescribed monitoring frequencies, and required quality control procedures.

The purpose of the research effort is to assess which monitoring parameters provide superior indicators or measurements at a municipal waste landfill operated as a bioreactor, and to the extent possible, determine if this operational technique represents an improvement over conventional landfill management. The QAPP contains a prioritized list of monitoring parameters assembled by researchers, based on previous bioreactor research and understanding of landfill operation. This landfill research is designed to operate within the existing regulatory requirements, and the experiment has the regulatory approval of The Commonwealth of Kentucky.

The experiment contains three key components as described in Table 3-1:

- a conventional RCRA Subtitle D landfill which serves as the experimental Control (Area 7.3);
- a bioreactor operational technique applied to an existing landfill cell, termed “facultative landfill bioreactor,” (FLB), also called “retrofit” (Area 5); and,
- a new bioreactor landfill cell called the aerobic/anaerobic landfill bioreactor (AALB), also called “as-built”(Area 7.4).

Each treatment and control (the control is considered a treatment for statistical purposes) is replicated with subcells to enhance comparisons and statistical understanding of data and trends.

As is common with full-scale research, there are several challenges associated with testing the behavior of operating landfills. In addition to the variability of waste composition for each vehicle load of refuse discharged at the site, other variable are present as part of this research investigation. For example, waste age, density, moisture content, and waste volume within each cell differ by treatments. Waste was first disposed in the FLB, three and half years later in the Control, and another year later in the AALB (see Section 3). Other confounding factors exist, including dissimilar cell geometries, and the inability to split incoming waste loads into the replicate cells. These differences in time sequence will need to be taken into account so as to interpret the superior performance of certain monitoring parameters.

As the project progresses, it is envisioned that the treatments and resulting data can be aligned according to time, geometry and amount of waste. Moreover, municipal solid waste is a highly heterogeneous material, and the purpose of this research is to observe the response and range of parameter trends that occur within landfill bioreactors when compared with 'normal', conventional landfill treatment. This research provides an opportunity to study and compare the performance of new landfill designs in the manner of controlled experiment. The results are expected to be variable but in kind with the variances typically seen with landfill research.

INTERIM FINDINGS

Based on results compiled through April 2003, there are already important and striking results at this stage of research. These are summarized below.

Landfill Operations

The bioreactor landfills have operated within RCRA Subtitle D and Clean Air Act requirements of a state-of-the-art municipal waste landfill. Leachate **head on liner** levels between control (conventional) and bioreactor treatment cells remain similar. Determination of leachate injection rate has been reasonably event free with minor operational issues addressed early on. There have been no slope stability issues associated with bioreactor or control treatments. The landfill gas extraction system has successfully used horizontal collection piping. Fugitive surface emissions were routine and corrected within the regulatory time requirements and have remained below methane concentration requirements. **Waste and leachate temperatures** are elevated as expected, indicating waste degradation. The AALB shows the highest mean temperatures at 28°C and 27°C, compared to the FLB at 20.0°C and 28.2°C, respectively. The Control cell had waste and leachate temperatures of 16.6°C and 16.6°C, respectively.

Trends in Physical, Chemical and Biological Parameters

Waste Settlement in the AALB is greater than in the other two treatments. This is probably due to the addition of leachate and resulting consolidation from seepage force. However, it is not statistically conclusive at this point in time (see Appendix D). There is more surface settlement in the FLB in the south east corner. This is consistent with the fact that this is where the new waste was added after sampling baseline solids sampling in June 2000 (See Figures 3-1, 3-2, and 5-6.)

Air space utilization values (AUF) have increased significantly for both treatments when compared to the Control cells, with the AALB approaching a calculated in-place waste density of 1,900 lbs/yd³. This may be partially explained by enhanced physical settlement due to moisture addition but it also represents the effect of biological decay based on the MSW solids data discussed below. (See Figure 5-8).

MSW Solids Data indicate that the changes in degradable organics are occurring in each of the treatment and control cells. In general, the AALB cells have shown the highest rate of change followed by the Control and then FLB cells. These data are shown with **BMP, cellulose, cellulose+hemicellulose/ lignin ratio**. This result was expected as the AALB treatment cell is

the most highly engineered and represents the most aggressive treatment of the experiment. (See Figures 5-40 through 5-44).

In the trend summary, (Appendix D), the **Leachate Ammonia and TKN** values tend to trend downward for FLB cells as was expected with this treatment. This was not seen in the control or AALB cells. (See Figures 5-23 and 5-28).

Fugitive Gas Emissions measurements were conducted for the FLB, AALB, and Control cells. Measurements were conducted using optical remote sensing. Radial and vertical scanning measurements using open-path Fourier Transform Infrared Spectroscopy (OP-FTIR) were conducted above surface and downwind from the sites.

The AALB was found to have 160 g/s of methane, considered a conservative estimate because complete capture of the gas plume was not possible. Additional sampling is being conducted. This report provides data for sampling conducted in September 2002. A description of the measurements and analysis of the results are presented in Appendix E.

The Final Report will help clarify more of these issues with a larger data set over a longer period of time. It is anticipated that this will be achieved at the end of this research effort. Our intent is to study other landfill sites to evaluate bioreactors under different conditions in the United States.

SECTION 2

PROJECT OVERVIEW AND OBJECTIVES

PROJECT OVERVIEW

In concept bioreactor landfills are designed to accelerate the biological stabilization of landfilled waste through increased moisture addition and other management techniques or procedures so as to enhance the microbial decomposition of organic matter. (Reinhart and Townsend, 1998). If the waste mass (or portions thereof) stabilizes more quickly than it would under conventional landfill operations, then certain benefits are anticipated.

Anticipated benefits include, that the receiving cell might accept more waste sooner and therefore the overall bioreactor landfill capacity should be greater. Enhanced waste stabilization should reduce the potential for future environmental problems because the generation and subsequent removal of high-strength leachates occurs earlier in the life of the leachate collection system and landfill liner. Landfill bioreactors may also improve the capture performance for landfill gas energy recovery projects through compressing the time during which methane generation is suitable for energy recovery concurrent with increased methane yields per unit of time. (Green, et al. 2000). Potential concerns of bioreactor technology currently include: the method of fluid addition; whether conventional landfill cell liners can sufficiently contain the increased fluid content; the amount of air space within these landfills; methods of determination of both moisture content and air space; and the effect on any fugitive gas emissions. Considering the potential environmental and economic benefits of bioreactor operations, there is great interest in this technology.

The purpose of this project is to test two types of landfills as bioreactors through the design, construction, and long-term operation of full-scale landfill cells. These two types of landfill, termed Facultative Landfill Bioreactor (FLB) and the Aerobic-Anaerobic Landfill Bioreactor (AALB), will each be compared to conventional landfilling techniques (Control). The initial objective of the project was to assess which parameters should be monitored in addition to those already monitored in conventional Subtitle D landfills, should either of these models, or a derivative thereof, be adopted as a standard method for landfill operation.

Rationale for Facultative Landfill Bioreactor

The Facultative Landfill Bioreactor (FLB) is based on a patent held by Waste Management, Inc. (U.S. Patent No.: US 6,398,958 B1, June 4, 2002). The patented process is a method by which the ammonia in the landfill leachate collected from the FLB is sequentially nitrified ex situ and then returned to the landfill where it is denitrified, resulting in a net loss of nitrogen from the landfill. The methodology was developed to control the cycling of inorganic nitrogen present in the landfill waste material and leachate. This aspect of control typically has not been addressed in previous bioreactor studies and has resulted in high concentrations of ammonia in

the leachate, leading to disposal problems and potential microorganism poisoning where the leachate is recirculated.

The process includes a method to manage the nitrogen cycle in the bioreactor landfill by the biological conversion of ammonia in the leachate to nitrate and nitrite. The nitrate/nitrite-rich leachate is returned to the landfill, thus promoting landfill biological stabilization and reducing or eliminating the need for ex-situ leachate disposal.

The reduction in leachate ammonia levels is achieved by withdrawing the leachate from the landfill and directing it into an attached growth nitrification unit. There the leachate will remain in contact with nitrification microorganisms, attached to fixed organic or inorganic substrates, for sufficient time to nitrify a minimum of 50 percent of the ammonia. The nitrified aqueous product is then returned to the landfill or to another landfill where it is biologically denitrified in situ, producing nitrogen gas. The denitrification step occurs in landfills undergoing either aerobic or anaerobic decomposition.

As discussed herein, this project is designed to test and compare the FLB method through the traditional existing landfill by injecting nitrate-containing leachate into landfill cells. This approach is based on two premises. The first is that the addition of leachate will moisten and promote degradation of the waste. The second is that microorganisms present in the landfill waste use nitrate in the leachate as a terminal electron acceptor for anaerobic metabolism. As nitrate containing liquid moves through the upper sections of the FLB, denitrifying bacteria will convert nitrate to dinitrogen gas. This transformation of nitrate-nitrogen to gaseous nitrogen should result in the net loss of gaseous nitrogen from the landfill. Comparisons will be made to a conventional landfill cell not receiving moisture addition (i.e., this project has no representative control where leachate addition is made under conditions of no enhancement of the leachate with nitrate).

Rationale for Aerobic-Anaerobic Landfill Bioreactor

The Aerobic-Anaerobic Landfill Bioreactor (AALB) is based on a patent held by Waste Management, Inc. (U.S. Patent No.: US 6,283,676 B1, September 4, 2001). This patent (titled "The Sequential Aerobic/Anaerobic Solid Waste Landfill Operation Patent") includes the design and apparatus used to build the AALB with the primary objective of increasing degradation of municipal solid waste to increase landfill density and hence capacity. The method design also aims to improve the quality of the degradation by-products including leachate and landfill gas, and reduce landfill gas fugitive emissions. The patented process described the method for constructing the AALB and applying sequential aerobic and/or anaerobic operations to the waste mass in sequential waste lifts.

In brief, the design involves placement of the first lift of waste material on top of the leachate withdrawal piping, followed by placement of the first piping layer on the top surface of the first lift; then placement of a second lift of waste on top of the first piping layer, followed by a second lift having a second lift top surface and placement of a second piping layer on the top surface of the second lift; and finally introducing air into the second lift using the first piping layer. Operation of this method is described in the patent.

As discussed herein, the project is designed to test and compare the AALB approach through the use of new landfilled wastes. The newly placed waste is treated aerobically, similar to composting, by injecting air into the waste for approximately 30 to 60 days. After aeration is discontinued, the waste is moistened with liquids, and anaerobic conditions are rapidly established. In Section 4, comparisons are made to Unit 7.3, a conventional landfill cell not receiving air addition or moisture addition (Control).

Project Setting

The Outer Loop Recycling and Disposal Facility (OLDRF) is located in Louisville, Jefferson County, Kentucky. The site, which has a total property area of approximately 782 acres, is located on the north side of Outer Loop Road, immediately west of Interstate Highway 65. The OLDRF is comprised of seven individual and separate landfill units, designated Units 1 through 7. Unit 1, Unit 2, Unit 3, and Unit 6 are inactive landfill units that are not receiving waste. Unit 4 is permitted as a construction and demolition debris (CD/D) landfill, and is an active unit. Unit 5 and Unit 7 are active permitted landfills and are the units of focus for this Bioreactor study. The Outer Loop Landfill is operated by Waste Management Inc. (WMI), and has been used for waste disposal for approximately 35 years. See Figure 2-1: Project Site Location Map.

The site is situated within the alluvial valley of the Ohio River; approximately nine miles southwest of river mile 614. The area is generally flat with elevations averaging 455 feet Mean Sea Level (MSL). The region is effectively enclosed by topographically elevated areas on the west, east and south. Elevations range up to 750 feet MSL in areas surrounding the site.

Topography and stream development in the area have been modified by construction and development activities of the region. Due to the flat topography, the clayey nature of the soil, and the relatively low elevation, the area is naturally poorly drained. To enhance surface drainage for the development of the region, several engineered drainage channels have been constructed in the area of the landfill. The channels drain toward the southwest, eventually discharging into the Ohio River. It has been observed that seepage of groundwater into the landfill occurs.

The average regional temperature is 14°C, ranging from -4 to 31°C. Average annual precipitation consists of 44.39 inches of rainfall, plus approximately 17.4 inches of snow. The number of precipitation days averages 125 per year, with 47 days being thunderstorms. Prevailing wind is from the south. Relative humidity varies throughout the day at an annual average of 58 to 76 percent. (Source: US Department of Commerce, National Climatic Data Center).

Project Ownership

The projects are under joint investigation by the U.S. Environmental Protection Agency (EPA) and Waste Management, Inc. through a 5-year Cooperative Research and Development Agreement (CRADA). The overall project is being managed, analyzed and operated by Waste

Management, Inc. at the Outer Loop Landfill located in Louisville, Kentucky. Personnel are made up of individuals from Outer Loop and the WMI BioSites program in Cincinnati, Ohio. The U.S. EPA is contributing to the management, oversight and analysis of the project. Table 2-1 provides a listing of the project participants and related project responsibilities.

TABLE 2-1. PROJECT PARTICIPANTS, AFFILIATION AND RESPONSIBILITIES

NAME	AFFILIATION	RESPONSIBILITY
Tony Barbush	WMI	Co-Principal Investigator; on-site operations
Morton Barlaz	North Carolina State University	Analytical measurements, quality assurance
David Burt	WMI	Oversight and quality assurance
David Carson	EPA	Co-Principal Investigator; project oversight
Greg Cekander	WMI	Program Owner; project oversight
Wendy Davis-Hoover	EPA	Co-Principal Investigator; project oversight
Charles Huber	Severn Trent Labs	Laboratory quality assurance
Douglas Goldsmith	Alternative Natural Technologies	Senior Scientist; sampling and analysis
Michael Goodrich	Microbial Insights	Manager; laboratory analyses
Roger Green	WMI	Co-Principal Investigator; field sampling oversight and database management.
Amy Haag	Severn Trent Labs	Manager; laboratory analyses
Gary Hater	WMI	Project Manager
Scott Jacobs	EPA	Quality Assurance Manager
Fran Kremer	EPA	Project coordination
Jim Markwiese	Neptune & Company, Inc.	Data validation
John Martin	EPA	Branch Chief; project oversight
Susan Thorneioe	EPA	Scientist; landfill gas and air emissions
Chuck Williams	WMI	Program Owner

State Approval

Approval for the AALB (constructed in Unit 7.4 A and B), and the FLB (retrofitted in Unit 5) was received from Commonwealth of Kentucky, Kentucky Natural Resources and Environmental Protection Cabinet, Department for Environmental Protection in 2001 (Permit No. 056-00028). Approval for the FLB study was issued in January 2001. Approval for the AALB study was issued in October 2001.

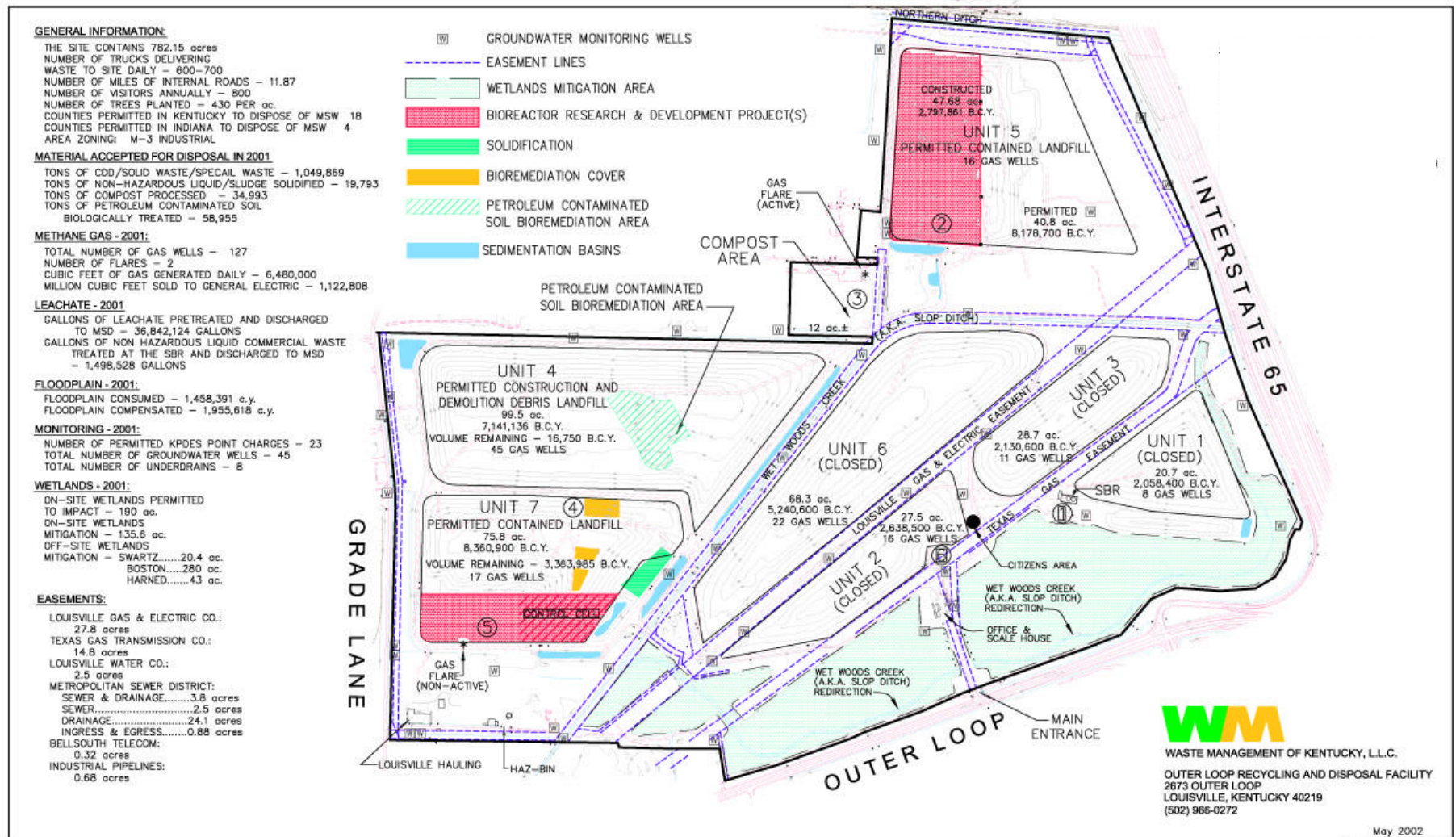


Figure 2-1. Project Site Location Map

PROJECT OBJECTIVES

The landfill research described herein involves two multi-year landfill bioreactor studies in comparison with control landfill cells. The FLB and AALB studies are underway and consist of separate and distinct landfill units, each composed of two paired cells. In contrast to most landfill bioreactor research conducted at the bench or laboratory scale, this demonstration project is a full-scale application of the stated bioreactor approaches and methods.

The overall project objectives for the landfill bioreactor studies at the Outer Loop Landfill Facility can be stated as:

- To engineer and install two alternative designs of large-scale bioreactors.
- To monitor sufficient parameters to understand the physical, chemical and biological activities and changes over time within the landfill bioreactors, with particular emphasis given to waste settlement, as well as the characteristics for in-place solid waste, leachate, and landfill gas.
- To compare and contrast the measured information with that of a conventional Subtitle D MSW landfill (dry entombment methodology) in order to evaluate differences due to the bioreactor treatments. But not necessarily to compare the two alternative designs.
- To incorporate statistical techniques to assess the effectiveness and protectiveness of the landfill bioreactor operational technique.
- To establish best practices and procedures required to operate landfill bioreactors.
- To establish the important and indicative parameters that should be monitored with respect to landfill bioreactor operations. (See discussion in Section 3 on Critical and Non-critical measurements).
- To obtain sufficient research data to enable improvements that might be applied to future bioreactors, both in an experimental capacity and ultimately as an alternative design and management method for future MSW landfills.

QA/QC Procedures

Quality assurance and quality control procedures are designed and incorporated into this investigation to ensure reliable analytical measurements of environmental samples in terms of typical data quality indicators. Required controls for precision, accuracy, method detection limits, completeness, comparability and representativeness are presented in Appendix C, the Quality Assurance Project Plan (QAPP). This document should be referred to for descriptions of QA/QC procedures.

Neptune and Company, Inc. was retained to performed data validation on selected sets of laboratory data for leachate and gas samples, including laboratory-generated data included in this report. As presented in Appendix C, observations and discrepancies in the project data were identified on a systematic basis. Subsequently, corrective steps were taken as warranted by the laboratory, Waste Management, and the EPA project team so as to make necessary adjustments and/or flag certain data points.

REPORTING

This Interim Report covers the period from the treatment cell initiations through April 2003. Monitoring is scheduled for a minimum period of the five-year contract life. A final report will be prepared and submitted at the conclusion of the project.

SECTION 3

PROGRAM DESIGN

The program design of the bioreactor project has been outlined in the Quality Assurance Project Plan for Landfill Bioreactor Studies (included herein as Appendix ?). The Outer Loop project is under joint investigation by the EPA and Waste Management, Inc., through a five-year Cooperative Research and Development Agreement (CRADA).

The Outer Loop Landfill is owned and operated by Waste Management, Inc., and has been used for waste disposal for approximately 35 years. The project's two multi-year studies are underway at the site, including the Facultative Landfill Bioreactor (FLB) study, and an Aerobic-Anaerobic Landfill Bioreactor (AALB) study. At Outer Loop, operation variables differ by separate and distinct landfill units, each composed of two paired (duplicate or replicate) cells.

In contrast to other bioreactor research, these demonstrations are large-scale research efforts at a full-scale operational landfill. The FLB study covers approximately 26.4 acres (total) in paired landfill cells; these cells are four to six years of age. The AALB study covers 12 acres (total) in paired one-year old landfill cells. The FLB cells were retrofitted for bioreactor operation whereas the bioreactor infrastructure in the AALB cells is constructed as waste is added. A separate unit of paired cells, containing approximately two to three year old waste, is used as the control for the FLB and AALB studies. Table 3.1 provides a summary of the cells under investigation.

TABLE 3-1 SUMMARY TABLE OF CELLS UNDER INVESTIGATION

LANDFILL UNIT	SUBUNIT	SUBCELL	TITLE	OPERATIONAL VARIABLES
5	1	A	FLB	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches.
5	2	B	FLB Duplicate	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches.
5	1	B	FLB	Addition of nitrate/nitrite enriched leachate from the SBR Unit through a series of retrofit surface trenches. Although subject to the FLB operation, participation in the study is restricted to a limited section of the sampling strategy and landfill gas collection.
5	2	A	FLB Duplicate	Addition of nitrate/nitrite enriched leachate from the SBR Unit through a series of retrofit surface trenches. Although subject to the FLB operation, participation in the study is restricted to a limited section of the sampling strategy and landfill gas collection.
7	3	A	CONTROL	Operated as a traditional Subtitle D landfill Unit.
7	3	B	CONTROL Duplicate	Operated as a traditional Subtitle D landfill Unit.
7	4	A	AALB	Air injected through a series of pipes constructed on the surface of each lift during waste placement, for a period of 30-60 days per lift. Moisture, primarily leachate, added after aeration is complete through the piping network.
7	4	B	AALB Duplicate	Air injected through a series of pipes constructed on the surface of each lift during waste placement, for a period of 30-60 days per lift. Moisture, primarily leachate, added after aeration is complete through the piping network.

LANDFILL UNIT DESCRIPTIONS

MSW Landfill Control (Control)

The conventional MSW landfill Unit 7.3 has been designated as the Control for the project. Unit 7.3 has been operated as a conventional RCRA Subtitle D landfill with no moisture or air addition, but is monitored and sampled in a similar manner to the FLB and AALB units to provide comparison data for the study. The Unit is located in the southeast corner of Unit 7. Unit 7 is located in the western portion of the Outer Loop Landfill complex, as shown on the Project Site Location Map in Figure 2-1.

Unit 7.3 consists of two-paired landfill cells, 7.3A and 7.3B. The Control unit is directly adjacent to Unit 7.4, which is the Aerobic-Anaerobic Landfill Bioreactor (AALB) portion of this study. A barrier layer is installed between units 7.3 and 7.4 (the Control and AALB) to prevent migration of leachate/moisture quantities, as well as landfill gas. This barrier layer consists of an impermeable clay along with an additional layer of permeable tire chips (to allow preferential movement of moisture and/or landfill gas at the unit edge).

The Control cells for this research project were selected as the best nearby representation of a Subtitle D waste mass. Prime attributes includes no past or ongoing moisture addition to the waste, and the filled areas had standard vertical landfill gas wells, common to the majority of U.S. Subtitle D sites. The Control area was originally filled starting in 1998. At the start of the project in 2001, solid waste in the control cells was nearing three years old, while the comparison bioreactor Unit 5, was approximately five years old, and the Unit 7.4 was at age zero.

In early 2001, WMI began processing a permit application for a facility horizontal expansion. In part, due to a recent federal rule by the Federal Aviation Administration about landfill siting and required distances from airports, the approval for the expansion was delayed for several quarters. Currently, this expansion is scheduled for Summer 2004.

The permit delays resulted in a significant decrease in available space to dispose of solid waste which, in turn, impacted the construction of Unit 7.4. Specifically, to complete the “as Built Bioreactors” in cells 7.4A and B, the vertical height for the remainder of Unit 7 (including the Control) had to be raised to final grades before the end of the project. At the beginning of the project, the initial volume in cell 7.3A was 822,387 in-place cubic yards and in cell 7.3B, 692,139 in-place cubic yards (ipcy). Over the remaining life of the project there will be a slight increase in both of these cells in order to bring the cells to final grade and allow for the completion of the “as Built” cells on the western slopes (see overall site plan given in Figure 2-1). The net result will be an increase of 7.3 percent in ipcy for cell 7.3A and 10.7 percent for cell 7.3B. Final grades are illustrated in Figure 3-1.

Volume changes in the Control are documented quarterly. Figure 3-2 illustrates the grading of the Control unit from September 1998. Below, in Table 3-2, is the surveyor’s geometric calculation of airspace in place at various times over the life of the project

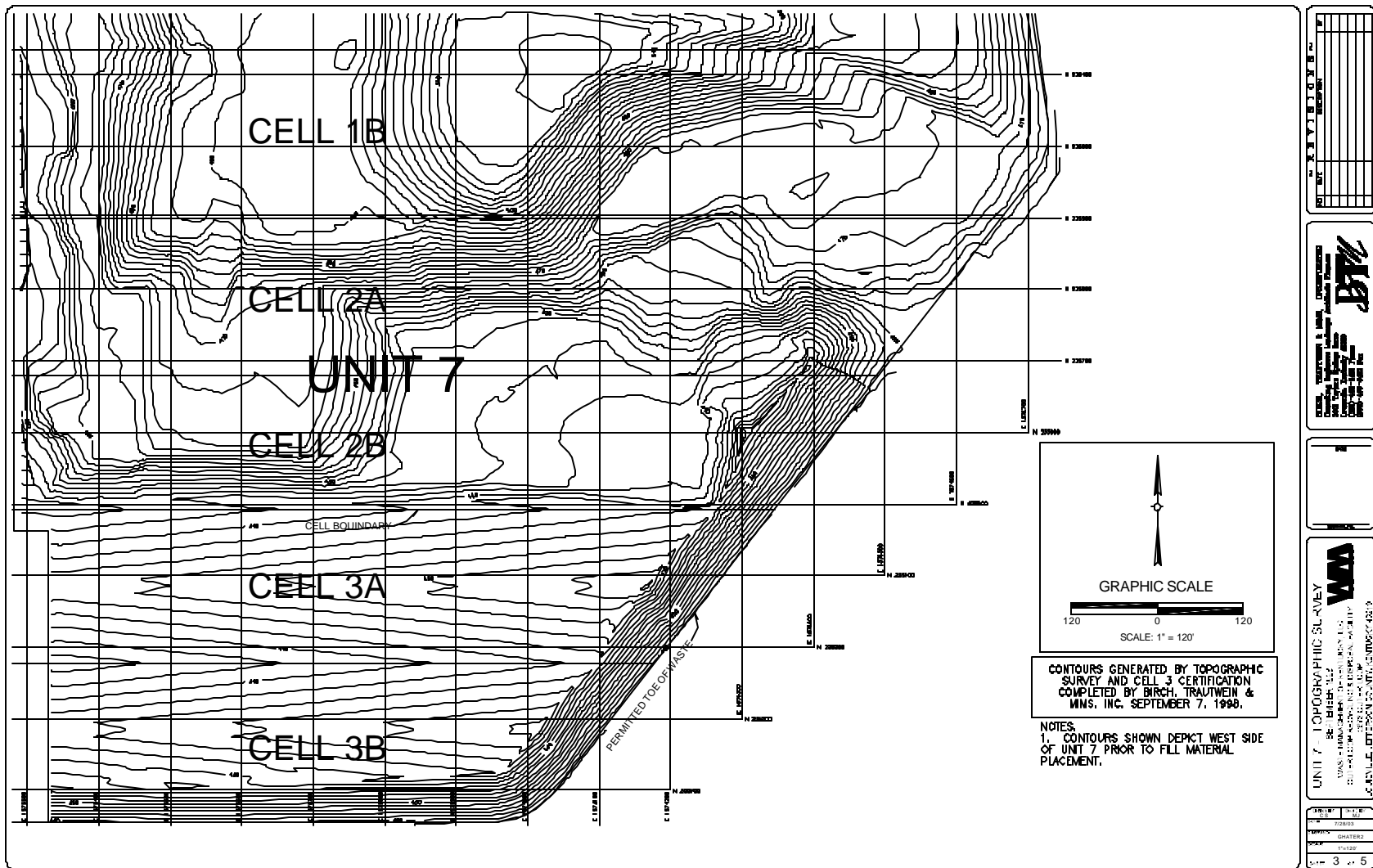


Figure 3-2. Grade of Control Unit, September 1998

TABLE 3-2 IN-PLACE CUBIC YARDS IN CONTROL OVER TIME

DATE	7.3A	% CHANGE	7.3B	% CHANGE
Fall 2001	822,387		692,139	
April 28, 2003	856,873	4.1%	730,021	5.4
Aug. 8, 2003	874,514	6.3%	747,662	8.0
Final, winter 04	882,908	7.3%	766,310	10.7

Concurrent with the waste additions to the Control, settlement plates are being placed on the slopes that are now being filled and three landfill gas wells may be added (the LFG wells are scheduled for Fall 2004). The settlement plates and new LFG wells will be monitored as part of the Control portion of the project to assess the benefits/impacts of this new loading on the Control cells.

Resampling of the waste mass is scheduled for 2004. For the control, the 1998-2000 waste mass and the 2003 – 2004 mass will be tracked separately. This may yield subsequent project comparisons between portions of the Control and the AALB that are of essentially the same age.

Leachate quantities from the Control will be affected from the opening of the southeast long-term cover until at such time the cell is re-covered. This opening is scheduled for about August 2003 until Spring 2004. During this period, the project may observe related changes in leachate cell volume and possibly leachate quality on account of periods of heavy precipitation.

FLB Process Description

Landfill Unit 5 has been designated the FLB for this portion of the study. The FLB Unit 5 is located in the northern portion of the Outer Loop Landfill complex, as shown on the Project Site Location Map in Figure 2-1. Unit 5 consists of four separate landfill cells, 5.1A, 5.2A, 5.1B and 5.2B, with Unit 5.1A (the most southern cell) and Unit 5.2B (the most northern cell) being the two primary FLB cells in the study.

Landfill Unit 5 began accepting waste in July 1995, a total of approximately 1,930,825 tons of waste was in place by October 1997. Retrofit activities took place in March through May 2001. Retrofitting the landfill unit was conducted by modifying it to become a bioreactor cell. Retrofit activities included installing trenches, moisture distribution and gas collection piping, thermocouples, and Oxygen Reduction Potential (ORP) probes. Figures 3-3 and 3-4 show the north-south cross-section and east-west cross section, respectively.

A series of horizontal trenches were installed up to 18 feet below the surface in Cells 5.1 and 5.2. Each trench contains a perforated pipe and was back-filled with a permeable material. The trenches were spaced approximately 60 feet apart. Six vertical gas extraction wells (twelve total) also were constructed in cells 5.1 and 5.2. The gas wells serve a dual purpose of collecting landfill gas and penetrating layers of soil cover placed during landfilling. Probes for measuring temperature and oxidation-reduction potential (ORP) were installed during vertical gas well installation in 2000. Additional thermocouples and ORP probes were installed during the 2001 retrofitting with the gas collection and liquid distribution piping. These probes were

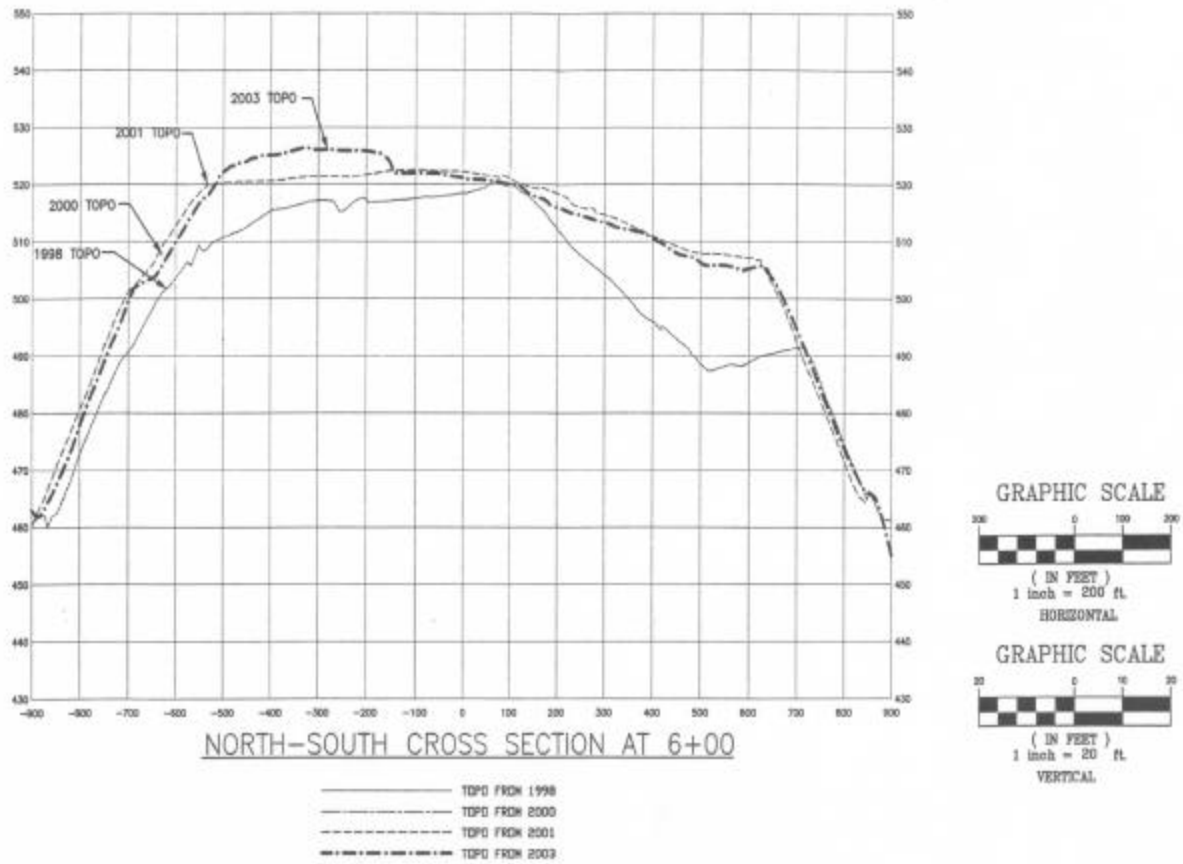


FIGURE 2

Figure 3-3. Unit 5 North-South Cross Section

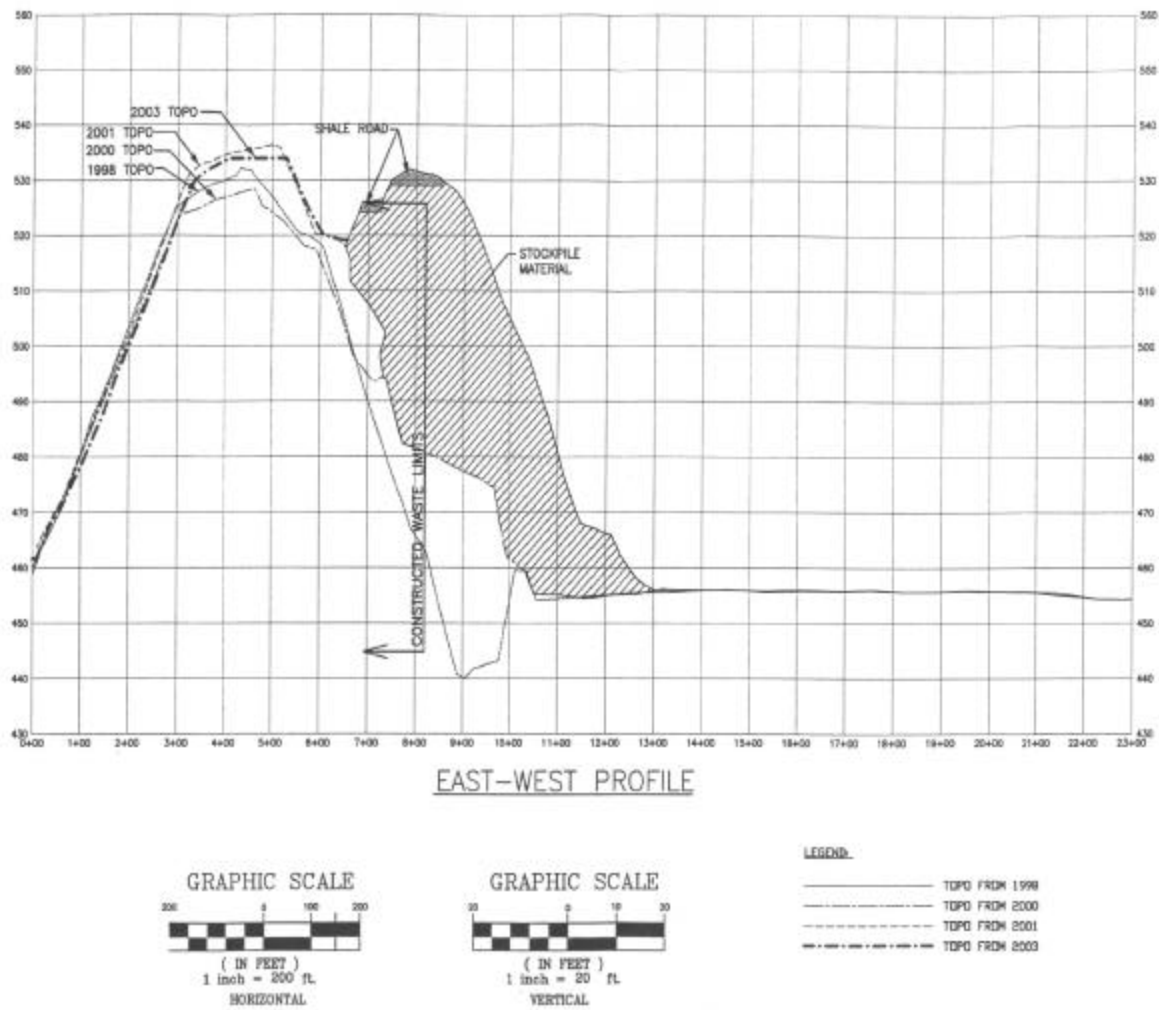


FIGURE 3

Figure 3-4. Unit 5 East-West Cross Section

placed in the trenches. Similar installations were made for the 7.3A and 7.3B Control cells. Figures 3-5 and 3-6 show the trenching system as well as the gas extraction well temperature probe placement.

Changes in the state of degradation in the waste mass, for example, the impact of nitrified effluent applied to the landfill in Unit 5 and subsequent denitrification, should impact the overall mass balance of nitrogen as the nitrate is converted to nitrogen gas. The data collected for COD, BOD, ammonia nitrogen, nitrite-nitrogen and nitrate-nitrogen, as well as leachate quantification are examined in Section 5-Results.

AALB Process Description

Landfill Unit 7.4 has been designated the AALB for this portion of the study. Unit 7.4 is located in the southwestern portion of landfill Unit 7. Landfill Unit 7 is located in the western portion of the Outer Loop Landfill complex as shown on the project site location map in Figure 2-1.

Unit 7.4A began receiving waste in July 2001 and 7.4B began receiving waste in September 2001. Units 7.4A and 7.4B are currently accepting waste, with approximately 959,993 cubic yards of waste in place as of March 2003.

Construction of the AALB features occurred concurrently with waste placement in Units 7.4A and 7.4B. The base layer of the unit consists of an initial, uncompacted layer of waste which serves as liner protection. AALB cells 7.4A and 7.4B were constructed in 15-foot vertical lifts. This shallow lift system results from grading waste to promote homogenization of the incoming solid waste. As each lift was completed, water was added to increase the moisture content of the waste. Perforated pipes then were placed at regular intervals across the top of the waste. The pipes were covered with a permeable media. Each lift of piping was then connected via a common manifold. The next lift of waste was then placed over the installed piping, and the construction sequence was then completed for each successive lift of waste. The buried piping system serves the three-fold purpose of aeration, moisture distribution, and gas collection. Figure 3-7 shows the end view of the north-south cross section of Unit 7.

As of April 2003, waste was no longer being accepted into the AALB study unit. Waste will be added again starting in late 2003 or early 2004.

TYPICAL LATERAL CROSS SECTION

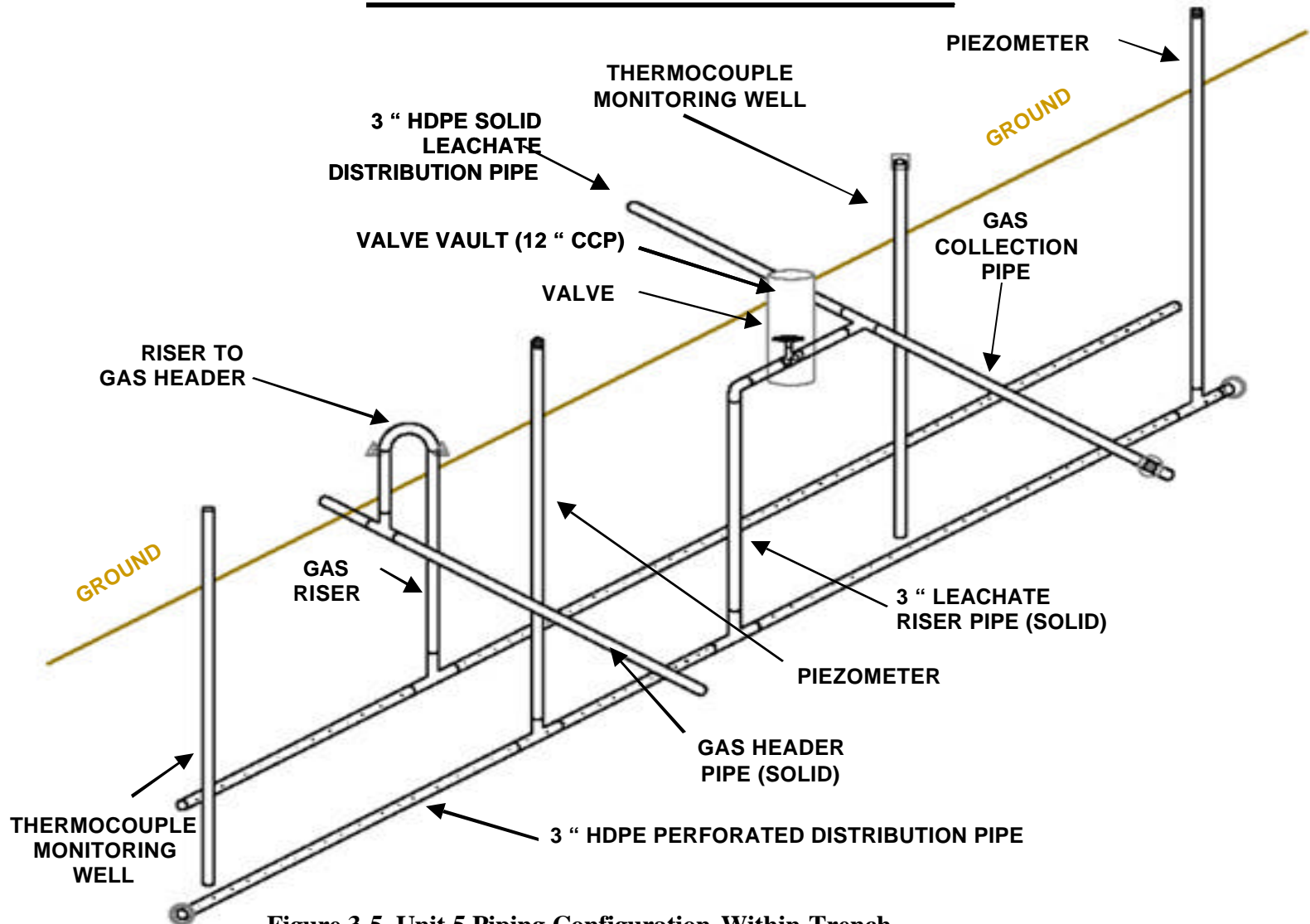


Figure 3-5. Unit 5 Piping Configuration Within Trench

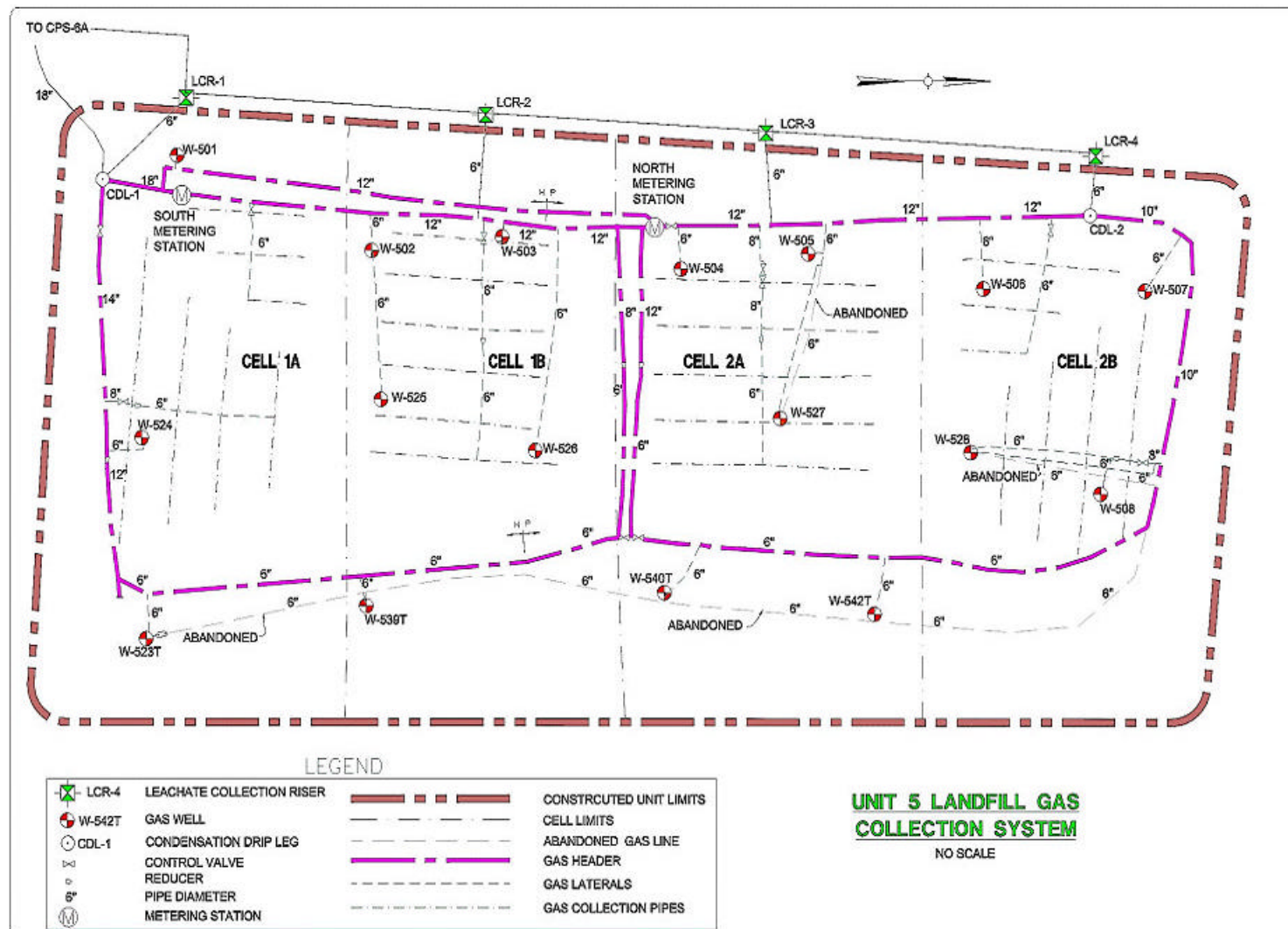


Figure 3-6. Unit 5 Gas Extraction Well and Temperature Probe Placement

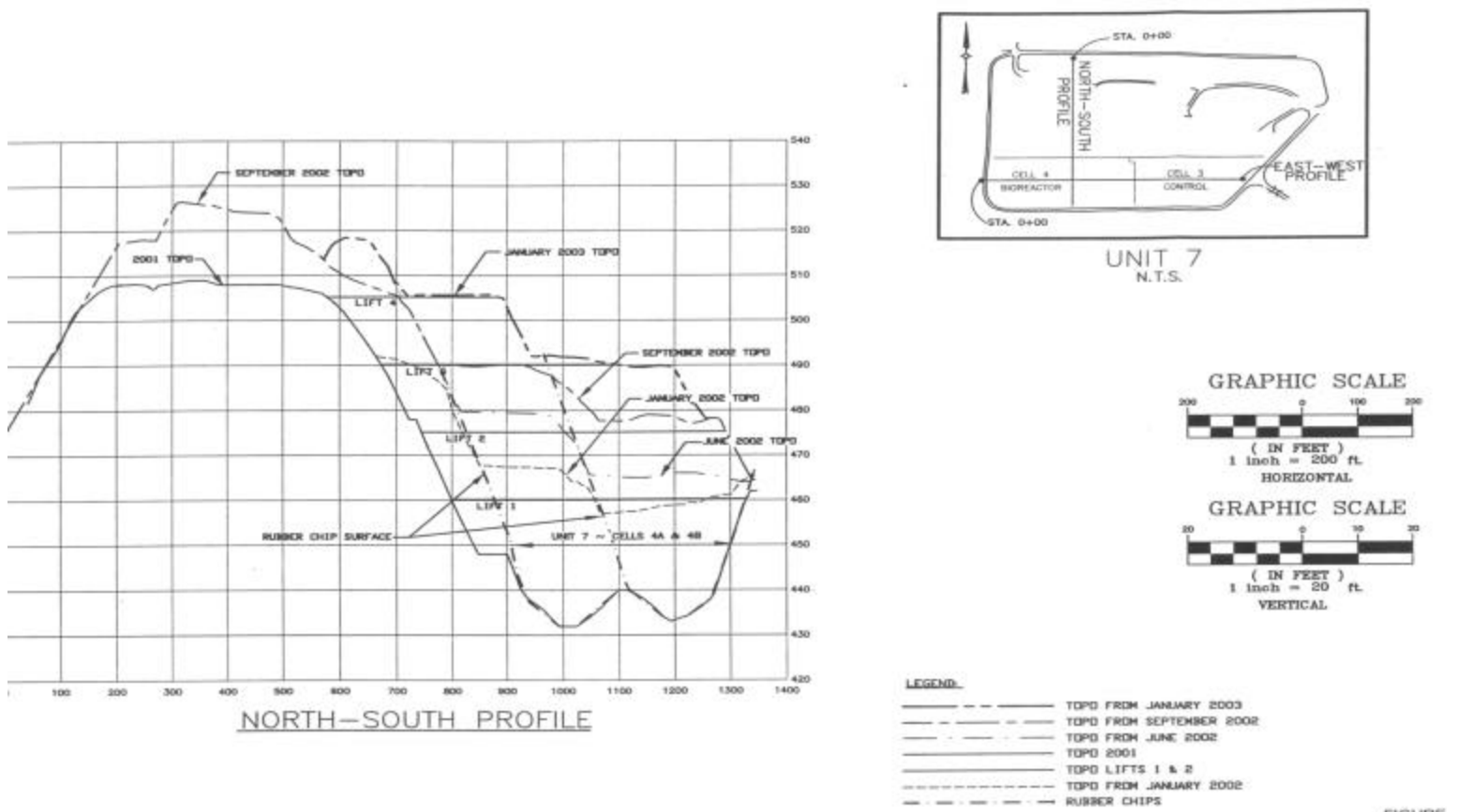


Figure 3-7. Unit 7 North-South Cross Section

BIOREACTOR TREATMENT STRATEGIES

Moisture Addition

Moisture addition is made to the FLB and AALB cells and not the Control cells. This moisture is primarily recirculated leachate, along with various other on-site moisture sources. For the AALB, the recirculated leachate is not treated prior to return to the waste mass.

For the FLB, recirculated leachate is treated through use of a chemolithotropic bacteria to take NH_4^+ to NO_3^- in the aerobic Sequential Batch Reactor (SBR). In concept, the denitrifying bacteria under anaerobic conditions in the landfill will use the NO_3^- as a terminal electron acceptor to form both N_2O and N_2 gasses. This nitrified leachate is introduced to the waste through the series of horizontal trenches that were installed in cells 5.1 and 5.2. The treated SBR effluent is monitored on a monthly basis for COD, BOD, ammonia–nitrogen, nitrite–nitrate nitrogen and phosphorous.

The treated leachate is pumped to a holding tank and distributed to the trenches via a force main and manifold for distribution to the FLB. Moisture sources other than the leachate, such as water from Outer Loop underdrain or sedimentation pond, or other liquid waste streams as permitted by regulation, may be used to augment the supply of leachate. These liquid sources are monitored in the same way as the SBR effluent in order to follow nitrogen dynamics. Moisture volumes additions are performed by the landfill operator and are dependent, in part, on precipitation, moisture levels in the waste, and other factors. Operator judgment is used as necessary to achieve and maintain the in-place waste at desired moisture levels, as discussed in Section 6. .

Air Addition

Aeration in the AALB study also is designed to achieve accelerated stabilization of solid waste. The purpose of the aeration process is to biodegrade organic matter in the waste in an initial aerobic composting stage prior to establishing the typical anaerobic conditions. Theoretically, by rapidly degrading the organic waste, the acid or lag phase (see below) of the landfill degradation process will be reduced significantly, resulting in a more rapid progression toward methane generation in the anaerobic stage. In addition, the accelerated degradation of easily degradable organic waste may result in improved leachate quality and a reduction in gaseous non-methane organic compounds (NMOCs) emissions. Aerating the uppermost lifts of the landfill should also establish conditions conducive to the biological oxidation of methane gas that is generated in the lower anaerobic lifts, thus reducing methane emissions. During and after aeration, moisture is added to control the temperature in the waste.

TIMELINE AND DATA COMPARISONS

Landfill units are filled sequentially (placement of waste in a particular cell is only initiated after the current waste-receiving cell is completely filled), therefore individual units in this study are not directly comparable with respect to time. The Control cells provide an adequate treatment reference by considering them as temporally offset from the treatment cells. For example, consider the comparison between FLB cells and the Control. As mentioned, FLB

waste is generally four to six years old and control waste is about two to three years old. In three years, Control waste will be approximately the same age as present-day FLB waste. Therefore, Control samples collected three years following the initiation of the FLB treatment should be comparable to FLB cell data from when leachate was first introduced. Figure 3-8 provides a timeline for comparison of significant events for this project.

FIGURE 3-8. TIMELINE OF EVENTS AT OUTER LOOP

	1995	
	JULY	FLB A & B start receiving waste
	1996	
	1997	
	OCT	FLB stopped receiving waste
Control 7.3A&B start receiving waste	1998	
	NOV	
	1999	
	2000	
	JUL	FLB A&B start receiving waste
CRADA approved and signed	OCT	
	2001	
	JAN	State approval received for FLB retrofit
FLB retrofit began	MAR	FLB stopped receiving waste
FLB retrofit complete	MAY	SBR Treatment construction began
AALB A starts receiving waste	JUL	
Aeration commenced within 30 days of completing each new lift	SEPT	AALB B starts receiving waste Aeration commenced within 30 days of completing each new lift
State approval received for AALB construction	OCT	
	2002	
	JAN	SBR Treatment Unit complete
	MAR	Addition of liquids to FLB Unit began
Addition of liquids to FLB Unit ceased	SEPT	
	2003	
	SEPT	First interim report due for submission

CRITICAL AND NON-CRITICAL PARAMETERS

Landfilled waste typically progresses through five phases of degradation, including: (1) adjustment or acclimation; (2) transition; (3) acidogenesis; (4) methanogenesis; and (5) maturation (Reinhart and Townsend 1998). This degradation process can be collectively considered as waste stabilization. At any given time, landfill cells may be characterized as experiencing one of the above phases. But because waste is deposited in a landfill cell over time (months to years), waste-stabilization phases tend to overlap and sharp boundaries between phases are not typical.

1. **Acclimation.** During acclimation, microbial populations are in a state of adjustment. Waste moisture tends to increase and available oxygen is consumed during this phase. The atmospheric-oxygen supply to the buried waste is diffusion limited and outpaced by the oxygen demand of bacterial respiration; consequently the concentration of oxygen in the landfill cell begins to decrease.
2. **Transition.** In the transition phase, conditions turn anaerobic as the available oxygen is consumed through the metabolism of readily degradable wastes. Complex organic matter is broken into simpler forms (e.g., organic acids) and energy that is not captured by cells during respiration is given off as heat. Waste and leachate temperature concomitantly increase during organic-matter degradation. Other respiration by-products (carbon dioxide and volatile organic acids) begin to increase in leachate.
3. **Acidogenesis.** During acidogenesis the accumulation of volatile organic acids reaches its peak due to metabolism and fermentation of organic matter. The increase in chemical oxygen demand and biochemical oxygen demand indirectly reflects this increase in degradable metabolites. In addition, the high concentration of acids increases hydrogen ion activity, reflected by decreased waste and leachate pH. In the near absence of oxygen, metabolism shifts to anaerobic bacteria capable of utilizing alternate electron acceptors (e.g., nitrate and sulfate).
4. **Methanogenesis.** In the methanogenic phase, the supply of most electron acceptors is exhausted. Methanogenic bacteria ferment organic acids to methane and carbon dioxide while other methanogens utilize CO₂ as their terminal electron acceptor. Consequently, gas (methane and CO₂) volume and production rates increase. Anaerobic respiration is a proton-consuming process and this is reflected by an increase in pH values in the waste and leachate.
5. **Maturation.** The maturation phase represents the end-point of landfill settlement (surface GPS measurements). The overall conversion of complex wastes to leachable organic acids and gaseous products also serves to reduce the waste volume and organic solids and to increase waste density. Maturation occurs when degradable organic matter, and consequently microbial growth, is limited. This is reflected by decreases in the biochemical methane potential and gaseous metabolic by-products methane and CO₂. Concentrations of organics in leachate remain steady but at substantially reduced levels relative to earlier phases.

It is expected, that the bioreactor treatments will increase the rate of transition through the various phases relative to the control. It is further expected that this enhanced transition to stabilized waste will be discernable with trend analyses.

The parameters selected for study for this project were divided into two basic groups termed critical and non-critical. The rationale for the parameter selection and grouping was based firstly on what parameters are currently monitored in conventional Subtitle D landfills and are useful indicators for optimal daily running of a landfill. Additional parameters were selected for research interest, based on previous landfill bioreactor study findings, ultimately cost evaluation also played a determining factor in the selection.

The critical measurements were selected as the best means to capture aspects of waste stabilization over time. The extend of parameters selected was designed to meet the initial objective to determine which parameters should be monitored in addition to those already monitored in conventional Subtitle D landfills, should either of these models be adopted as a standard method for landfill operation. Ultimately it is anticipated that a combination of the critical and non-critical grouped parameters will provide sufficient information over the life of the project to understand and evaluate these bioreactor designs, as compared with conventional landfilling techniques, and meet the objectives set for this research project.

TREND MONITORING

Settlement

Settlement of the fill is monitored quarterly through GPS measurements of elevation as an indication of biological stability. The numerous GPS sample points provide a data set with which to evaluate waste settlement. In addition to GPS measurements and survey data, settlement plates have been installed to measure settlement and stability of the landfill test cells.

Pneumatic settlement cells and conventional settlement plates were installed to help define the limits of the test cells in areas they are laid over existing waste. It is expected that the pneumatic settlement cells will provide accurate measurement of settlement at depths greater than that of conventional settlement plates in operating landfills.

A total of eight settlement plates were installed in Unit 5; seven of these plates remain in place to date. Unit 7.4 currently has two settlement plates in place. A total of three plates have been located in the control area to measure the settlement rates as a comparison. The top elevation of each plate was surveyed prior to the start of liquid injection.

Leachate

Leachate is collected from each of the cells in the study. The design of the landfill units (paired cells) is such that, with exception of Unit 5, each cell is separated from the surrounding cells. With respect to Unit 5, 1,000 feet of waste separate sample locations for cells 5.1A and 5.2B. The median of the two treatment cell observations from each sampling event will be calculated, resulting in a single time series for each treatment and control. These time series are used to assess trends, or lack thereof, for those characteristics and analytes measured in the leachate.

Municipal Solid Waste

Incoming solid waste is weighed on scales as it enters the landfill and prior to disposal in certain cells. In addition to weight, waste volume is calculated based on quarterly survey events using global positioning system on a fixed GPS grid. In addition, changes in surveyed slope points and an annual aerial photometric survey are used to supplement volume calculations. Waste composition is recorded according to the type of incoming waste: municipal solid waste; special waste; solidification waste; biosolids; asbestos; and construction and demolition debris.

Along with the two-dimensional analyses outlined for the leachate and the landfill gas, three-dimensional analyses are done for the municipal solid waste. If the treatment is more effective at one depth than another, incorporating depth into the MSW data assessment may identify it.

Settlement and fill are monitored quarterly through GPS measurements of elevation as an indication of stability. The numerous GPS sample points provide a data set with which to evaluate waste settlement. Specific techniques on the employed technique of GPS surveying are provided in Section 4.

Landfill Gas

Gas sampling for CO₂, O₂ and CH₄ are performed weekly. NMOC, HAPs and methane surface emissions monitoring are performed quarterly. Similar to leachate, gas sampling occurs at one point per cell where the gas extraction wells come to the collection point. The gas extraction wells are located systematically, approximately equidistant from one another. The number and location are selected to be representative of the cell. A description of the gas sampling procedure and analyses are given in Section 4.

Methane Surface Emissions: Regulatory Monitoring

Surface emissions are monitored on a quarterly basis in accordance with the requirements specified by the New Source Performance Standards (NSPS) and Emission Guidelines (EG) for municipal solid waste landfills in 40 CFR 60.755. Methane concentrations are measured within 5 to 10 cm (2 to 4 in.) of the landfill surface using the CEC-Landtec SEM 500. Methane surface concentrations are monitored around the perimeter of the collection area along a pattern that traverses the landfill at 30-meter intervals and where visual observations indicate elevated concentrations of landfill gas.

Fugitive Gas Emissions Study

Fugitive gas emissions are those gaseous emissions that are not captured through the engineered LFG collection system. Optical remote sensing (ORS) was used to evaluate fugitive gas emissions (primarily methane) for the FLB, AALB, and Control study units. At least three rounds of fugitive gas emissions testing are to be conducted at this site to estimate impacts on fugitive emissions from landfill bioreactors when compared to controls. Three rounds of testing will be completed by Fall 2003, with final results available in the Spring 2004. The most recent available set of measurements is presented in Appendix E.

SECTION 4

METHODS

This section provides a summary of both operational and sampling/analysis methods used during this investigation at the FLB, AALB and Control sites (Quality Assurance Project Plan, 2003).

OPERATIONAL METHODS

Moisture Addition

Moisture addition for this project was primarily leachate addition to the FLB and AALB test cells. It was achieved via gravity-fed injection through the horizontal piping or trench systems so as to increase significantly the moisture content of these wastes when compared to the control cells. Rates of gravity-fed moisture addition varied from approximately 5 to 80 gallons per minute.

Excessive moisture addition can result in leachate seeps or breakouts, and reduced performance of landfill gas collection wells and trenches. Consequently, moisture addition events included site monitoring by the landfill operator. Similarly, operator judgment was used to reduce such moisture additions during periods of precipitation or to increase moisture addition quantities during periods when the waste mass appeared to be drier. The amount and timing of moisture addition were established through a series of trial events so as to increase volumes added to the waste mass without compromising the leachate containment or landfill gas collection systems. Field procedures and practices used for moisture addition at Outer Loop are discussed in Section 6 - Field Observations.

Facultative Landfill Bioreactor (FLB) --

Leachate collected from Unit 5 is recirculated through an on-site Sequential Batch Reactor (SBR) containing fixed chemolithotrophic bacteria that reduce the ammonium level by converting it to nitrate/nitrite. The leachate remains in contact with nitrification microorganisms for sufficient time to nitrify to achieve an ammonia concentration of less than 50 mg/L. The nitrified aqueous product is then pumped to a holding tank before being returned to the FLB through a series of gravity-fed horizontal trenches. These trenches were constructed in the surface of the landfill after waste placement was complete. Other sources of liquid may be used to supplement the leachate, including water from the under drain or sediment pond, or other liquid sources permitted by the landfill facility permit.

Aerobic-Anaerobic Landfill Bioreactor (AALB) --

Leachate and other moisture quantities are applied to the surface of the Unit 7 AALB units and through perforated piping manifolds connected to four tanks used to accumulate liquids from various sources. These sources have included Unit 7 leachate, various commercial liquids, surface water, and under drain water. The tanks' gravity feed to both the surface and buried manifolds; the surface manifold was moved on an ongoing basis to different locations of the

waste mass so as distribute moisture more evenly onto the waste (as determined by the landfill operator). In practice, moisture quantities were added to the lift of waste immediately below the lift of waste being aerated.

Air Addition

Aeration of the AALB unit was initiated within 30 days of completing a new lift of waste and was accomplished on an intermittent basis. Prior to commencing, moisture was added to the working face of the lift to be aerated. Aeration was performed after a lift of waste was placed to cover the aeration piping and the prescribed moisture addition was completed. Air addition was achieved through the horizontal piping installed between the lifts of the landfill, primarily using a blower at a pre-established rate between 200 to 1,000 scfm (Hater et al. 2001), supplemented on occasion with an air compressor. The rate and duration of air addition was dependent on the waste lift and, in particular, waste temperature. The air pressure across the header was balanced using a pressure gauge once the blower had been operational for 24 hours. The aeration face was watered on an approximate weekly basis.

Aeration was performed over a period of approximately 30 to 60 days or until waste temperature reached 60°C. Aeration times generally varied with:

- food content of waste;
- moisture content of incoming waste and evaporation rate; and
- ambient air and blower air temperature.

To assess the progress of the aerobic composting stage, ongoing monitoring was performed for odors (subjective), landfill gas composition (field instrument), and waste temperature (in situ probes). These parameters provide both information on when to reduce or terminate the air addition, and also as a safety procedure to avoid subsurface fires. For example, changes in landfill gas composition, meaning a decrease in methane content and/or a rise in carbon monoxide content, could be indicative of subsurface fire conditions.

Waste temperature rise was used as the key measure to stop or reduce air addition. If a waste temperature probe reached 80°C, or if after reaching 60°C, a temperature probe increases by 10°C or more during any 48-hour period, air addition would be terminated. See also Section 6 - Field Observations.

SAMPLING AND ANALYTICAL METHODS

The following sampling and analysis methods were applied to all of the tested landfill cells. Methods used during this investigation were concordant with EPA Standard methods contained within SW 846.

Sampling Frequency

An extensive program for sampling was developed for this project. A summary of sampling frequency is provided below, one sample was taken for each parameter at the given frequency from each of the locations: FLB 5.1, FLB 5.2, Control 7.3A, Control 7.3B, AALB 7.4A and AALB 7.4B, with the exception of those taken from the Municipal Solid Waste (MSW). See Field Measurements section for further discussion of the Waste Settlement protocol.

Sampling locations are discussed herein and were intended to reflect representativeness over the entire cells under investigation. For example, each cell's leachate drains to a central sump, samples collected at sumps were therefore assumed to be representative of the entire cell. Similarly, sampling from landfill gas extraction wells and soil boring locations were assumed to represent cell and subcell on an ongoing basis. Generally, samples were taken from central locations within cells so as to avoid edge effects.

TABLE 4-1. SAMPLING FREQUENCIES IN MATRICES OF INTEREST

MATRIX: Leachate		MATRIX: Municipal Solid Waste	
PARAMETER	FREQUENCY	PARAMETER	FREQUENCY
Head on Liner	Continuous	Oxygen Reduction Potential	Daily (up to 250)
Leachate Production	Continuous	Temperature	Daily (up to 250)
Chemical Oxygen Demand	Monthly	Waste Settlement	See Field Measurements
Biochemical Oxygen Demand	Monthly	Cellulose/lignin	30 samples annually
Ammonia-nitrogen	Monthly	Organic Solids	30 samples annually
o-Phosphate	Monthly	Biochemical Methane Potential	30 samples annually
Total Phosphorus	Monthly	Waste Moisture	30 samples annually
Nitrate-nitrogen	Monthly	Appearance	30 samples annually
Nitrite-nitrogen	Monthly	pH	30 samples annually
Total volatile organic acids	Monthly	MATRIX: Landfill Gas	
Temperature	Monthly	LFG flow/production	Weekly
pH	Monthly	CH ₄ , CO ₂ , O ₂ Field	Weekly
Conductance	Monthly	CH ₄ , CO ₂ , O ₂ Summa	Quarterly
Volatile Organic Compounds	Quarterly	Non-methane organic compounds	Quarterly
Semi-Volatile Organic Cmpds	Quarterly	Hazardous Air Pollutants	Quarterly
Total Kjeldahl Nitrogen	Quarterly	Surface emission monitoring	Twice Quarterly
Total Dissolved Solids	Quarterly		
Sulfate	Quarterly		
Chloride	Quarterly		
Potassium	Quarterly		
RCRA Hazardous Metals	Quarterly		

Field Sampling Techniques

Specific sampling procedures have been developed by the EPA and vary with the sample matrices and specific analyses. The types of containers, methods of preservation and holding times are identified in Table 4.2.

Leachate --

Leachate samples were taken at the drain sump areas for Units 5.1 and 5.2, 7.3A and 7.3B, 7.4A and 7.4B. Samples were obtained at regular time intervals at one sampling location. Leachate samples were collected directly from the tap or port on the riser pipe. This port is located at the point near where the leachate riser daylights to surface. Leachate was pumped from the sump through the riser pipe and collected from the valved port. Switching the riser pump from automatic mode to hand mode (essentially turning the pump off) prior to sampling was shown in subsequent sampling events to be an effective procedure for obtaining an adequate volume of leachate.

Leachate samples were collected in the following sequence: COD, BOD, volatile organic acids, pH, temperature, VOCs, SVOCs, TKN, ammonia-N, nitrate-N, nitrite-N, total metals (including potassium), o-phosphate, total phosphate, chloride, sulfate, TDS and conductance. To obtain a representative sample, effluent was purged prior to collecting the actual sample. The purge volume was estimated by multiplying the time the sample line was open by leachate flow rate (30 gal/min) and recorded on the Leachate Sampling Information Form.

Municipal Solid Waste (MSW) --

Solid waste samples were collected annually at systematically chosen boring locations. The cell was divided into six sections; each section was divided into 3x3 square meter grids and a square randomly chosen within a grid as the boring location for that section. The equivalent boring location was used for sampling in the remaining sections. The edges of the cell were not sampled. When drilling could not be initiated or completed for whatever reason in a selected location, a randomly selected square adjacent to the original location was selected, but only for that section where drilling was incomplete.

A drill rig equipped with a 3-foot diameter bucket auger was used to sample each location in 10-foot vertical sections. One representative sample, consisting of a 10 to 20 gallon composited aliquot, was collected for each section. The initial 10 feet of material generally was discarded as it usually contained significant quantities of soil. As the boring advanced, each 10-foot section was extracted from the auger and the appearance and temperature of the waste recorded. At least 30 baseline waste samples were collected from cells in Unit 5 and Unit 7.3 in 2000. Six baseline samples were collected from 7.4A in November 2001 and six from 7.4B in February 2002. Additional samples were collected from all cells in October 2002. More than 30 for Unit 5 cells 5.1A and 5.2B, only 23 for cells 7.4A and 7.4B, and more than 30 for cells 7.3. The reason for this is six borings are placed in each cell. Waste samples are collected for each 10-ft increase in depth as the boring is advanced. The number of samples was dependent on the depth of the boring.

The composite waste samples were sealed in plastic bags and placed in a cooler for shipment to the laboratory. These included samples for organic solids, pH, moisture content, biochemical methane potential, and cellulose/lignin ratio at the frequency designated.

Temperature and ORP of the in-place MSW were monitored by type K-thermocouples (Hanna Model No. HI 766 C1). The data communications/gathering system that the probes are connected to currently record the temperature or ORP reading for each probe, once every 30 minutes. Probes returning erratic temperature readings, based on historic temperature control charts, were investigated and the erratic results flagged.

Landfill Gas --

Gas monitoring was done at the installed gas monitoring point within each cell to monitor activity within the landfill bioreactors and control areas. Information recorded for gas sampling was logged on a Gas Sampling Information Form.

Field monitoring was performed using a GEM 2000 instrument (see Field Measurements) on a weekly basis (see Field Measurements below). Samples were collected for laboratory analysis of methane, carbon dioxide, and oxygen by EPA Method 3, non-methane organic compounds (NMOCs), by EPA Method 25C, and volatile organic hazardous air pollutants (HAPs; Appendix J) by Compendium Method TO-14 on a quarterly basis. These samples were collected in 6-liter SUMMA[®] passivated stainless steel canisters at the gas monitoring point.

Preservation and Handling

Samples collected for laboratory analysis were transported to the lab within 24 hours via an overnight shipping company. Samples requiring cooling for purposes of preservation were packaged in coolers and maintained at 4°C using crushed ice. Ice was packaged in large Ziploc baggies to prevent leakage onto sample containers. The laboratory was contacted prior to the day of shipment. The laboratory recorded the shipment temperature (of a temperature blank) upon arrival and significant variances in temperature (i.e. greater than 4°C) were immediately reported to the WMI project Co-Principal Investigator responsible for field activities.

Project personnel for field activities completed a sample collection narrative form, a record of activities carried out by the sampling team. The team member responsible for the sampling project completed the narrative and it traveled with the Chain of Custody (COC). The instructions laid out in the Project QAPP for the completion of the COC, sample handling and storage, and the transfer of sample custody were adhered to at all times. The sample collection information was also recorded on an analytical data sheet for field-testing parameters such as pH, specific conductance, gas surveys etc.

Samples collected for laboratory analysis were identified with standard labels attached to the sample containers. The standard format detailed in the Project QAPP was utilized to uniquely identify all samples. All field documentation and project logbooks were maintained according to the QAPP (Quality Assurance Project Plan, 2003), which is included as Appendix B.

TABLE 4-2. CONTAINERIZATION, PRESERVATION AND HOLDING TIMES

PARAMETER	SAMPLE VOLUME & CONTAINER	PRESERVATION	MAX. HOLDING TIME
Inorganic Tests			
Ammonia-nitrogen	500ml*, P, G. ¹	Cool 4°C, H ₂ SO ₄ to pH<2	28 days
BOD	1000ml, P, G.	Cool 4°C	48 hours
COD	1000ml, P, G. ¹	Cool 4°C, H ₂ SO ₄ to pH<2	28 days
Conductance (leachate)	P, G.	None required.	Analyze immediately.
Chloride	500ml, P, G.	None required	28 days
Potassium	500ml, P, G.	Field acidified to pH<2 with HNO ₃	28 days
Kjeldahl Nitrogen	1000ml, P, G. ¹	Cool 4°C, H ₂ SO ₄ to pH<2	28 days
RCRA Metals	1000ml, P, G. ¹	Field acidified to pH<2 with HNO ₃	6 months (Hg 28 days)
Nitrate-nitrogen	1000ml, P, G.	Cool 4°C	48 hours
Nitrite-nitrogen	1000ml, P, G.	Cool 4°C	48 hours
o-Phosphate	500ml, P, G.	Cool 4°C, filter in lab if necessary	48 hours
Total phosphorous	500ml, P, G. ¹	Cool 4°C, H ₂ SO ₄ to pH<2	28 days
Total dissolved solids	500 ml, P, G.	Cool 4°C	7 days
Temperature (leachate)	P, G.	None required.	Analyze immediately.
pH (leachate)	P, G.	None required.	Analyze immediately.
pH (waste)	1000ml wide-mouth, P, G.	Cool 4°C	7 days
Moisture (MSW)	1000ml wide-mouth, P, G.	Cool 4°C	28 days
Sulfate	50ml, T, P, G.	Cool 4°C	28 days
Specific Conductance	500ml, P, G.	Cool 4°C	28 days
Organic Tests			
Organic solids	Double-wrapped plastic garbage bag. ²	Cool 4°C	21 days
Cellulose:lignin	Double-wrapped plastic garbage bag. ²	Cool 4°C	28 days
BMP	Double-wrapped plastic garbage bag. ²	Cool 4°C	21 days
Volatile organic acids	8oz. Amber glass, Teflon-lined septa	Cool 4°C	10 days
VOC	3x40ml glass, Teflon-lined septa	Cool 4°C, no headspace	7 days
SVOC	2x11 Amber glass, Teflon-lines septa	Cool 4°C	Extract – 7 days Analyze – 21- 40 days
Microbial studies	500ml P, G Sterile bag	Cool 4°C	24 hours
CH ₄ , CO ₂ , O ₂	6-liter, summa	Not required	7 days

*ammonia sample taken from COD bottle

¹Sample bottles will be sufficient volume to prevent sample loss due to effervescence upon acidification.

²Wrapped samples placed in polyethylene trays with lids and these filled trays are then placed in a (un-cooled) plastic bin.

³This study was performed in addition to the requirements of the QAPP.

P – Plastic

G – Glass

T – Teflon

Sources: SW 846 Methods, 40 CFR 136, and Standard Methods for the Examination of Water and Wastewater.

Analytical Methods

A set of critical and non-critical parameters was established for each matrix. The methods used to measure each of these are presented in the following tables (Analytical Method References 14 to 18).

TABLE 4-3. ANALYTICAL METHODS FOR LEACHATE

CRITICAL		NON-CRITICAL	
PARAMETER	METHOD	PARAMETER	METHOD
Chemical Oxygen Demand	410.4 (C)	VOC	8260 (B)
Biochemical Oxygen Demand	405.1 (C)	SVOC	8270 (B)
Temperature	Cole-Parmer Thermocouple*	o-Phosphate	365.2 (C)
pH	Field electrode*	Total Phosphorus	365.2 (C)
Volatile Organic Acids	Microbial Insights SOP	Total Kjeldahl nitrogen	351.2 (C)
		Total dissolved solids	160.1 (C)
		Sulfate	300.0 (A)
		Chloride	300.0 (A)
		Potassium	6010 (B) (prepared according to 3005)
		Conductance	Field electrode*
		RCRA Haz. Metals	6010/7470 (B) (prepared per 3005)
		Ammonia nitrogen	350.1 (C)
		Nitrate nitrogen	353.2 (C)
		Nitrite nitrogen	353.2 (C)
		Head on Liner	Pressure Transducer*
		Leachate Production	Totalizing Flow Meter*

TABLE 4-4. ANALYTICAL METHODS FOR MUNICIPAL SOLID WASTE

CRITICAL		NON-CRITICAL	
PARAMETER	METHOD	PARAMETER	METHOD
Waste Temperature	Cole Parmer Thermocouple*	Oxidation-reduction Potential	Field ORP Electrode*
Waste Settlement	GPS survey*	Cellulose:lignin ratio	ASTM E-1758-95/Barlaz (R&D Method)
Organic Acids	Barlaz R&D Method	Appearance of Waste	Field Observation*
Moisture Content	Barlaz R&D Method		
pH	US EPA 9045C		
Biochemical Methane Production	Barlaz R&D Method		

TABLE 4-5. ANALYTICAL METHODS FOR LANDFILL GAS

CRITICAL		NON-CRITICAL	
PARAMETER	METHOD	PARAMETER	METHOD
CH ₄ , CO ₂ , O ₂	GEM 2000*	Surface Emission Monitoring	NSPS/FID mod. Method 21*
CH ₄ , CO ₂ , O ₂	Method 3C	Non-Methane Organic Carbon	EPA Method 25C
Gas Collection	Orifice plate*	Hazardous Air Pollutants	Compendium Method TO-14
Gas Volume	GEM 2000*		

* Field Measurements.

Field Measurements

Equipment used for field measurements was calibrated according to manufacturers' instructions.

In-Situ Municipal Solid Waste Temperature and ORP --

Temperature and Oxidation Reduction Potential (ORP) of the in-place waste were monitored by type K thermocouples (Hanna Model No. HI 766 CI) wire connected to a standard Cole-Parmer thermocouple panel meter on the surface. Temperature and ORP readings were made on a daily basis per cell. No calibration was required.

Leachate Temperature, pH and Conductance --

Leachate temperature was measured using a Hanna Instruments Model HI 991301 pH/conductance/temperature probe on a monthly basis. Calibrations were performed per the manufacturer's specifications.

A 500-ml or other suitable, clean, container was used to collect a sample of leachate from the same sampling port used for leachate quality sampling, immediately after collection of the quality samples. Each parameter was measured from the same sample.

The pH meter was capable of measuring pH to +/- 0.002 units. The probe was calibrated before use each time using three buffer solutions that bracketed the expected pH. Accuracy was determined by re-measuring one of the three buffer solutions as a sample. The instrument had a temperature accuracy of $\pm 0.2^{\circ}\text{C}$ and resolution of 0.1°C . Though the measurement was not in-situ, it was typically made within 30 minutes of sample collection.

An Accumet conductivity cell (Fisher Scientific, Cat No. 13-620-166) with a measurement range of 1000 to 200,000 $\mu\text{S}/\text{cm}$, a cell constant (K) of 10.0cm^{-1} and accuracy of +/-0.5 percent was used to make the measurements. The probe was calibrated with standard solution of 12,880 $\mu\text{S}/\text{cm}$ ($\mu\text{mho}/\text{cm}$) @ 25 degrees C (Hanna Instruments, Cat No. HI 8030L). The cell had a one point automatic calibration, though several standard solutions were used to check the range. Leachate conductivity measurements typically fell in the 4-18 mS/cm range.

Head on Liner and Leachate Production --

An in-place pressure transducer measured the head on the landfill liner and leachate production was quantified with a factory-calibrated totalizing flow meter (one per cell).

Landfill Gas Composition and Volume --

A factory-calibrated orifice plate was used to measure the volume of gas collected by the landfill gas collection system. Gas temperature was measured using a Reotemp bimetal thermometer permanently fixed to the gas header, metering station piping, or gas well near the orifice plate. The thermometer is of stainless steel construction, approximately 3-inch diameter, with a dial direct read face.

Gas field analyses were performed for methane, carbon dioxide, and oxygen using a GEM 2000, and in accordance with procedures given in EPA Method 3C. This instrument is a portable field gas analyzer and uses a self-compensating infrared detector. The instrument was calibrated prior to use per manufacturer specifications using 50:35:0:15 CH₄:CO₂:O₂:N₂ and 0:0:4:96 CH₄:CO₂:O₂:N₂ gas mixtures. Additionally, the calibration was checked again after sample measurements with these gas mixture standards. Calibration gases for the GEM 2000 were obtained from CES Landtec and included concentrations that bracket the expected measured concentration and a "zero" gas (e.g. nitrogen). Concentration readings for carbon dioxide and methane had to be within 15 percent of the actual concentration or sample duplicate; the tolerance for oxygen was ± 30 percent. Zero gases registered at no greater than 5 percent of the span of the instrument.

After calibration, the instrument was connected to a gas sampling port using flexible plastic tubing. Gas was drawn into the instrument by an internal pump and analyzed. Results were date and time stamped and data logged by the instrument. Gas standards for CH₄, CO₂ and O₂ were analyzed twice daily on the day of sampling to evaluate accuracy objectives. Gas volume measurements were made by electronically logging three consecutive measurements of gas quality (methane, carbon dioxide, oxygen, and balance gas) and flow (differential pressure, static pressure, gas temperature, and flow rate) to the GEM 2000 for each sample point. The mean value for each of these measurements was recorded as the value for each parameter of interest.

Surface Emissions Monitoring --

Surface emissions monitoring was performed for methane using the field instrument CEC - Landtec SEM-500. This is a hand held portable flame ionization detector used to monitor surface emissions at landfills. The instrument was calibrated prior to use according to the manufacturer's specifications.

Surface emissions monitoring was performed in accordance with the requirements specified by the New Source Performance Standards (NSPS) and Emission Guidelines (EG) for municipal solid waste landfills in 40 CFR 60.755. Methane concentrations were measured within 5 to 10 cm (2 to 4 in) of the landfill surface using the field instrument. Methane concentrations were measured following the procedures in EPA Method 21, except that "methane" replaced all

references to "volatile organic compounds" (VOC) and the calibration gas was 500-ppm methane in air [§ 60.755(d)]. Methane surface concentrations were monitored around the perimeter of the collection area and along a pattern that traverses the landfill at 30 -meter intervals. In addition, prescribed monitoring included taking measurements where visual observations indicated elevated concentrations of landfill gas (e.g., distressed vegetation, cracks or seeps in the cover).

Waste Settlement --

Surface settlement of the fill was monitored quarterly through Global Positioning Survey (GPS) measurements of elevation. The number of measurements taken per quarter is tabulated below. Unit 5 cells 5.1 and 5.2 are each comprised of two subcells, with each subcell having 20 GPS points.

TABLE 4-6. NUMBER OF GPS POINTS PER LOCATION

LOCATION	NUMBER OF GPS POINTS
FBL 5.1 (A&B)	40
FBL 5.2 (C&D)	40
Control 7.3A	20
Control 7.3B	20
AALB 7.4A	20
AALB 7.4B	20

GPS measurements were performed using the Trimble model 4800. Sampling points within a cell were selected according to the following criteria:

1. Every sampling event was initialized from a known point and within a ± 5 cm span for the horizontal and vertical coordinates of the known point. If sampling within a cell was interrupted, the system was reinitialized from the known point before sampling was resumed.
2. Sampling was initiated if the root mean square reading from the system was less than or equal to 10.
3. The positional dilution of precision (a measure of the relative dispersion of satellites in the sky) reading was less than or equal to 6 before the system was initialized.

In addition to the plots described above, standard high and low points and contours were measured. One of every 20 points measured by GPS was randomly selected and re-sampled. These methods were used to confirm that the positional accuracy of the GPS readings was sufficient to meet the analytical needs of the investigation (including conformance with the QAPP), and that the GPS measurements made were accurate, reliable, and comparable.

In addition to GPS measurements and survey data, settlement plates were installed to provide a localized indication for refuse settlement within the landfill test cells. Settlement plates were placed in the proximity of wells and trenches to measure the surface movements during the study. The top elevation of each plate was surveyed prior to initiation of moisture addition.

Figures 4-1 and 4-2 provide GPS and settlement plate locations for Units 5 and 7, respectively.

Fugitive Gas Emissions Study --

Sampling and analytical methods involved with measuring fugitive gas emissions at the Outer Loop Landfill are presented in Appendix E.

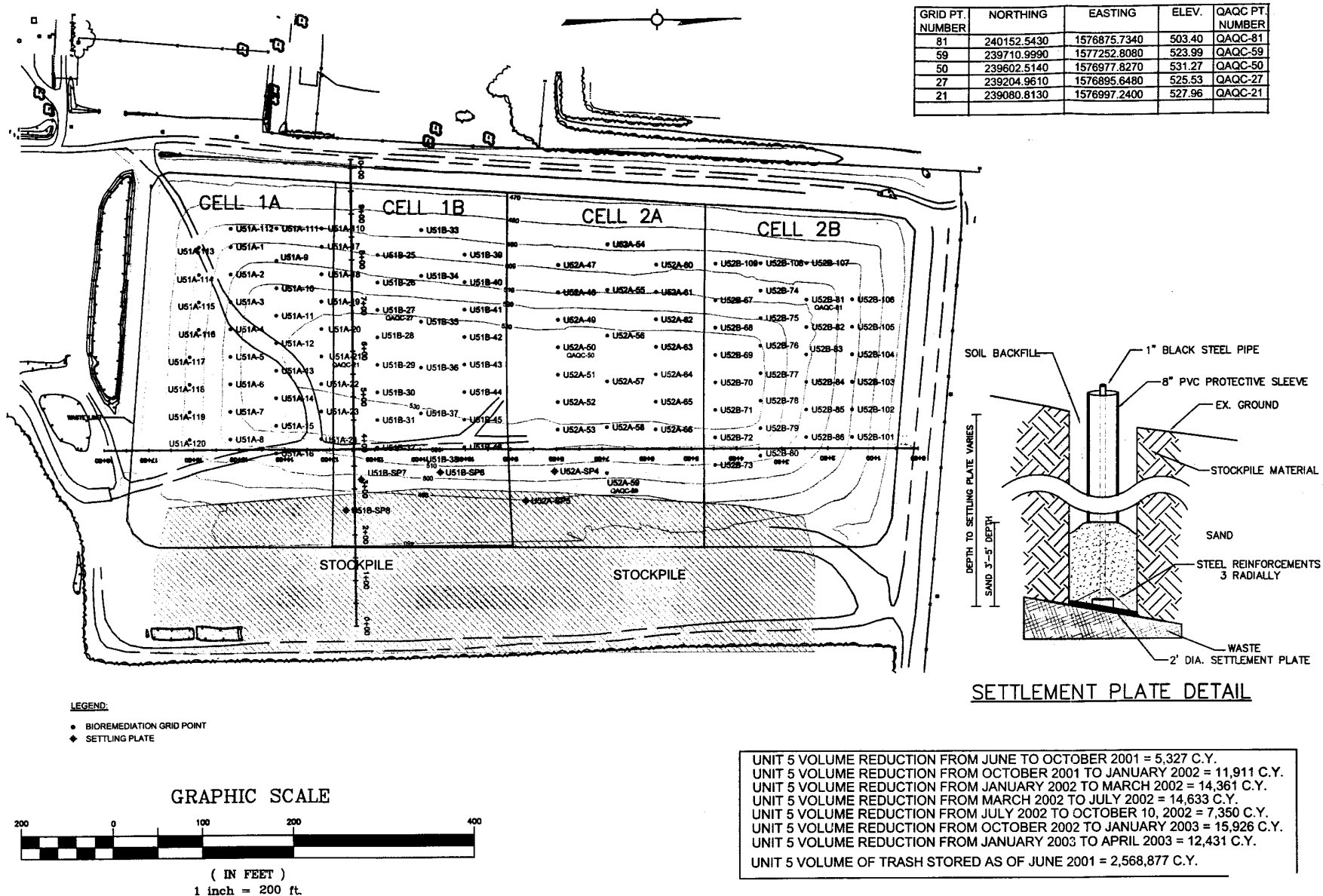
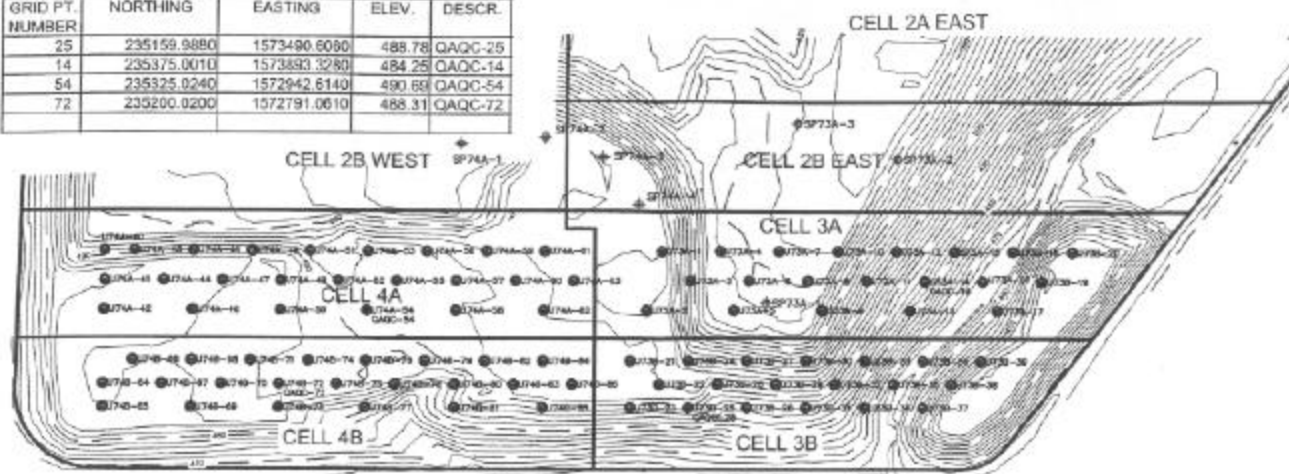


Figure 4-1. Unit 5 GPS Point and Settlement Plate Locations



GRID PT. NUMBER	NORTHING	EASTING	ELEV.	DESCR.
25	235159.9880	1573490.6080	488.78	QAQC-25
14	235375.0010	1573893.3280	484.25	QAQC-14
54	235325.0240	1572942.6140	480.69	QAQC-54
72	235200.0200	1572791.0610	488.31	QAQC-72



BIO-REACTOR VOLUME SUMMARY:
 CELL 2: 6,433 C.Y.
 CELL 3: -725 C.Y.*
 CELL 4A: 95,829 C.Y.
 CELL 4B: 37,068 C.Y.
 * Negative Volume indicates Settlement.



LEGEND:
 ● BIOREMEDIATION GRID POINT
 ⊕ SETTLING PLATE

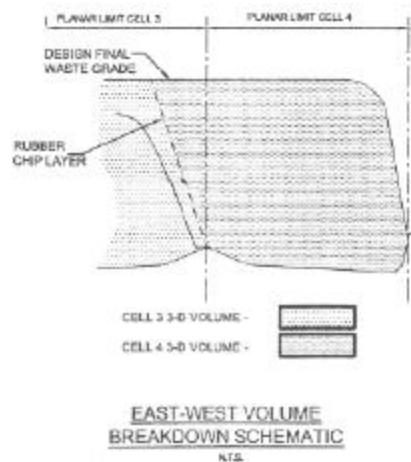
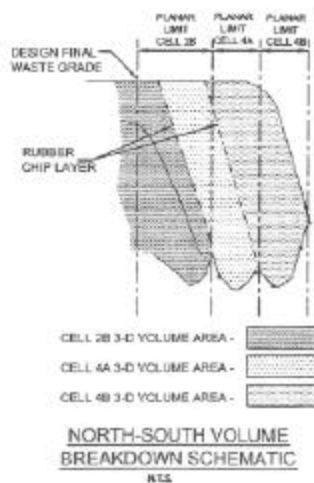
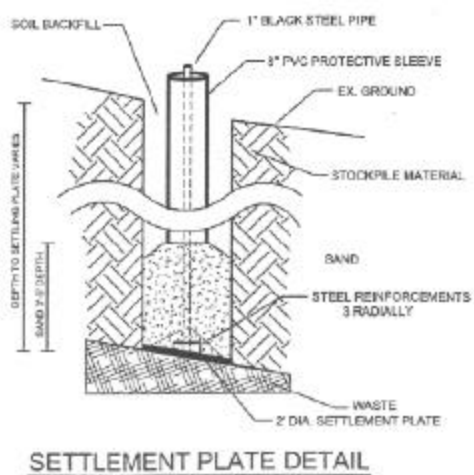


Figure 4-2. Unit 7 GPS Point and Settlement Plate Locations

SECTION 5

RESULTS AND DISCUSSION

This section summarizes the sampling and field monitoring results for the Control, FLB and AALB study units. Discussion of these results is provided herein, with supporting statistical analysis included as Appendix C. Monitoring activities began in June 2001 in accordance with the methods described previously in Section 4. The data documented herein are for the period from cell initiation through April 2003.

DATA VALIDATION

Three independent Data Validations have been performed for all critical and non-critical analysis of leachate, landfill gas (LFG), Municipal Solid Waste (MSW) and settlement parameters. On the basis of these audits, the data was amended as necessary. The data included in this report has been subject to this independent validation, all observations and findings documented in the validation reports have been addressed in the data presented.

STATISTICAL ANALYSIS

It is the intention of this project to use statistical methods to evaluate and compare data trends identified by the extensive parameter monitoring program. Given the immature status of the project and the present temporal non-correlation discussed previously, it would be premature to fully explore any apparent trends observed in the data collected so far for the purposes of this interim report. However, various statistical techniques were investigated and applied to some of the data collected to date, in order to assess the most appropriate method of displaying the results and evaluate the techniques for future application.

For a full account of the statistical techniques applied see Appendix C. In summary, data was expressed in Time Plots or, where more appropriate, Box Plots or Histograms. Although not applied in the following section, best fit curves were provided in the statistical evaluation of the leachate Time Plots. Levelplot of Settling Height Change (LOESS) or “contour” plots were applied to the GPS settlement data for qualitative purposes only, no rigorous statistical analysis was performed on this.

Statistical methods were then evaluated as a means to detect any statistically significant trends and slope estimates. For the leachate parameters the Mann-Kendall test was applied, and for the waste settlement the Shapiro Wilk Normality Test and Wilcoxon Rank Sum Test were evaluated.

Analysis of covariance was performed for the leachate data between replicate pair cells. Each unit consists of two cells that are considered duplicates or replicates of each other.

- Control 7.3A is a replicate of Control 7.3B
- FLB 5.1A is a replicate of Control 5.2B
- FLB 5.1B is a replicate of Control 5.2A
- AALB 7.4A is a replicate of AALB 7.4B

This set-up ensures that any apparent trend seen in a given cell can be evaluated against that seen in a similar, duplicate cell exposed to similar operational conditions, which theoretically therefore should behave in the same manner.

The statistical analysis techniques applied here did not reveal any statistically significant trends, it did, however, identify significant outliers which affected the statistical analyses. These results were not unexpected and supported the assertion that it was somewhat premature to assume a model structure for the many parameters given the limited data currently available. The heterogeneous nature of the patterns seen for many of the parameters do not yet give rise to a common model that can be used to make comparisons. The following section presents and summarized the data so far, without offering in depth statistical evaluation.

SUMMARY OF PERIODS OF LEACHATE AND AIR ADDITIONS

The following Table 5-1 provides a timetable of the periods of leachate and air addition to the bioreactor treatment cells. Although included in this report for reference purposes only, this information will be used in future analysis of the data to correlate with any data trends identified and improve understanding of these systems.

TABLE 5-1. TIMETABLE OF LEACHATE AND AIR ADDITION

PERIOD	FLB 5.1	FLB 5.2	AALB 7.4A	AALB 7.4B
3/21/02 to 10/11/02	Fluid Addition			
2/16/02 to 10/11/02	Fluid Addition	Fluid Addition		
6/18/02 to 7/4/02			Air Addition	Air Addition
7/15/02 to 7/27/02			Air Addition	Air Addition
7/30/02 to 8/12/02			Air Addition	
2/4/02 to 2/14/03			Air Addition	Air Addition
2/18/02 to 3/27/03			Air Addition	Air Addition

Note: Liquid Addition to the AALB cells is essentially continuous beginning with installation of the first lift of waste in each cell.

WASTE VOLUMES AND SETTLEMENT

Various parameters were measured to monitor waste volume changes over time and ultimately, waste settlement in each of the cells under investigation. The results documented in this report apply the Control Unit (7.3 A and B), the FLB (Unit 5.1A and 5.2B) and the AALB (Unit 7.4 A and B).

Summary of Waste Volume

Gross volume for in-place waste and other materials was measured for each of the cells on a quarterly basis using surveying techniques. This has been graphically represented in Figures 5-1, 5-2, and 5-3 for the Control, FLB and AALB, respectively.

Waste deposition in Control Cells 7.3 A and B began in late 1998. Both cells have been filled at approximately the same rate with 7.3A presently having the slightly greater volume of 655,165 m³ versus 558,174 m³. Initially the waste volume in both increased rapidly as waste was deposited, bringing the total waste volume in both cells to 1,022,136 m³ by March 1999. Additional waste has continued to be deposited in both 7.3 A and 7.3 B resulting in a gradual increase in volume. By end of March 2003 there was 1,213,339 m³ of waste in place. The trend is a result of the frequency and volume of waste deposited versus the rate of settlement and degradation of the waste, hence over certain periods a drop in volume is observed as the rate of settlement is greater than the rate of deposition. See Figure 5-1.

Waste deposition in FLB Cells 5.1 and 5.2 began in July of 1995. This landfill received a total of 1,930,825 tons of waste by October 1997. An additional 154,924 tons of waste were added between July 2000 and March 2001. No further waste has been deposited since that time and waste volume measurements for the period June 2001 through December 2002 show a steady decrease in each of the four subcells A, B, C and D. The volume reduction over the period represents a 2.5 percent decrease in A, 2.6 percent in B, 2.5 percent in C and 3.4 percent in D. See Figure 5-2.

Waste deposition in AALB units 7.4A and 7.4B began in July and September 2001, respectively. The waste volumes in place for both AALB units are showing an increase in waste volume over time because each continues to receive waste on a daily basis. By end 2001 there was 22,3971m³ total waste in place in both cells, 680,947m³ by end 2002, and 734,011m³ by March 2003. See Figure 5-3.

Figure 5-1. Waste Volume vs. Time for Control Cells

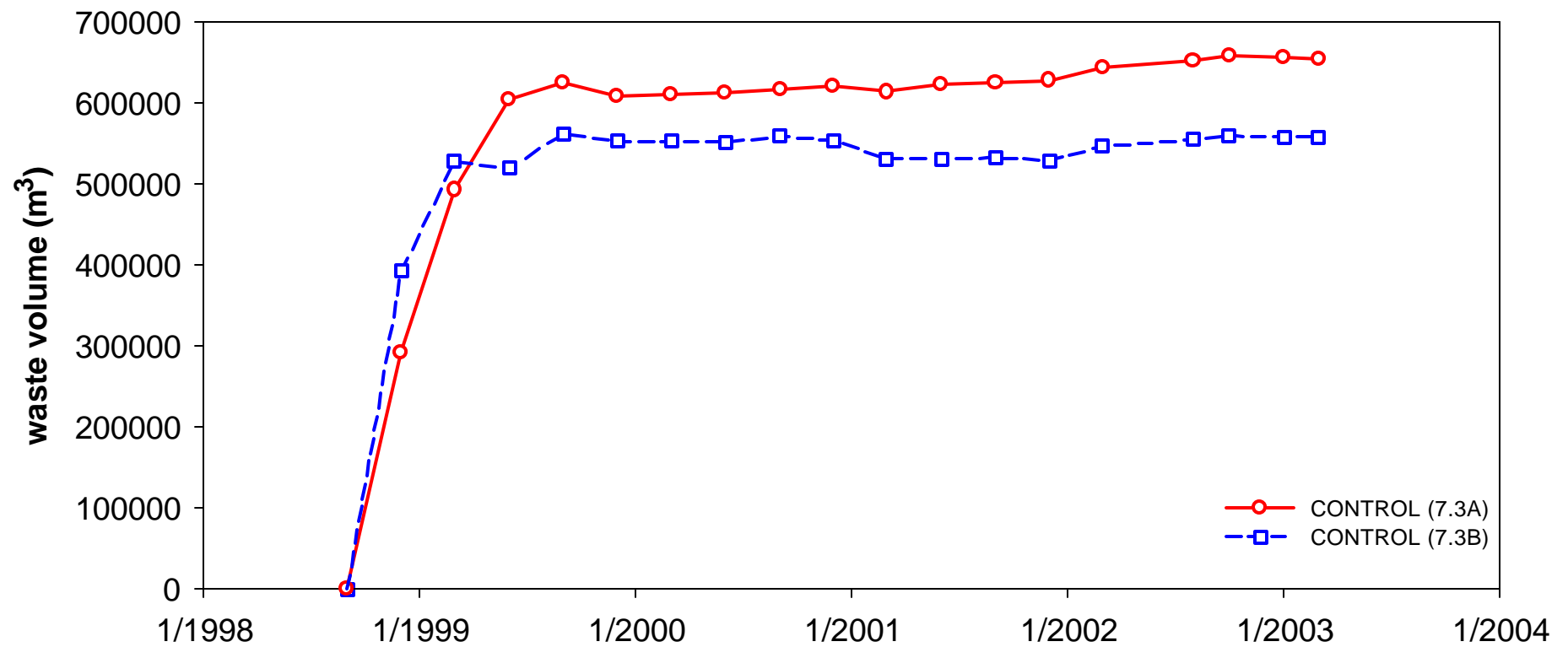


Figure 5-2. Waste Volume vs. Time for FLB Cells

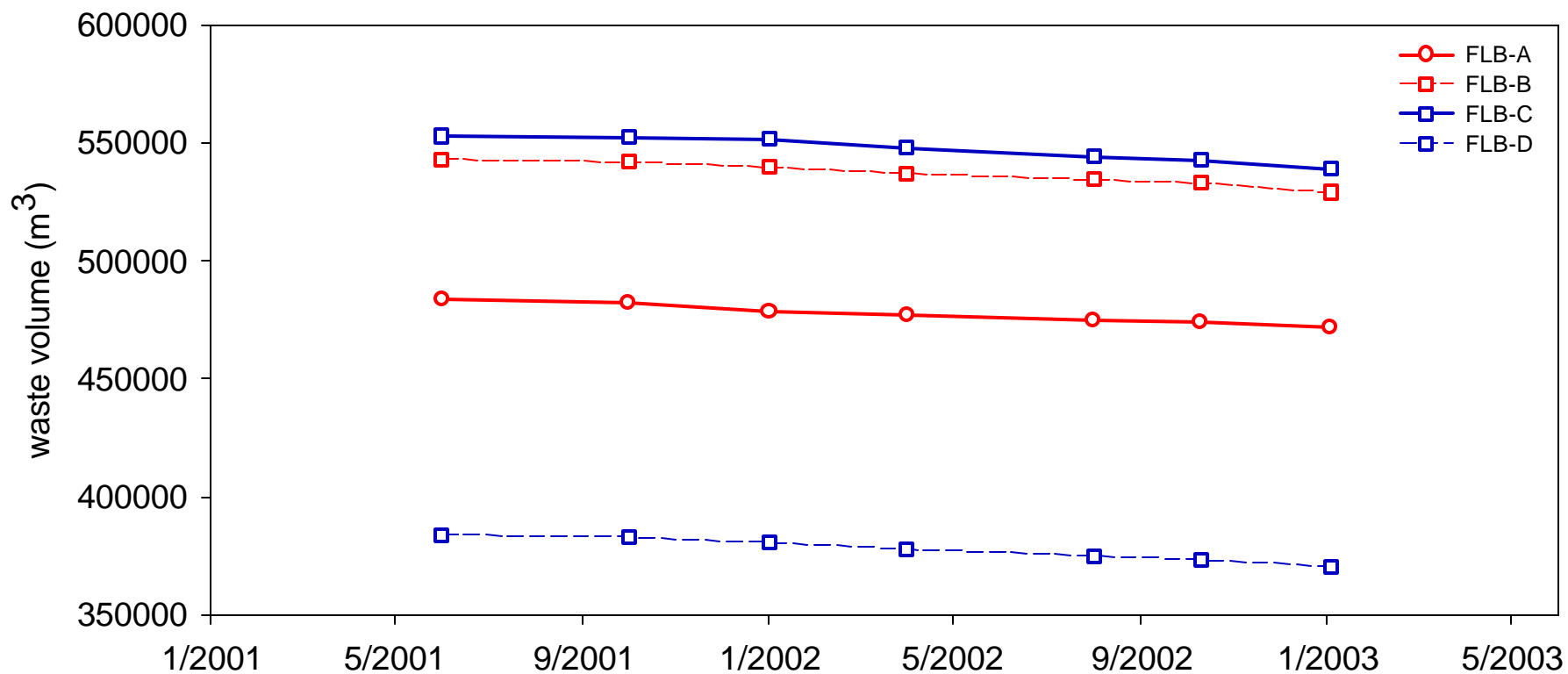
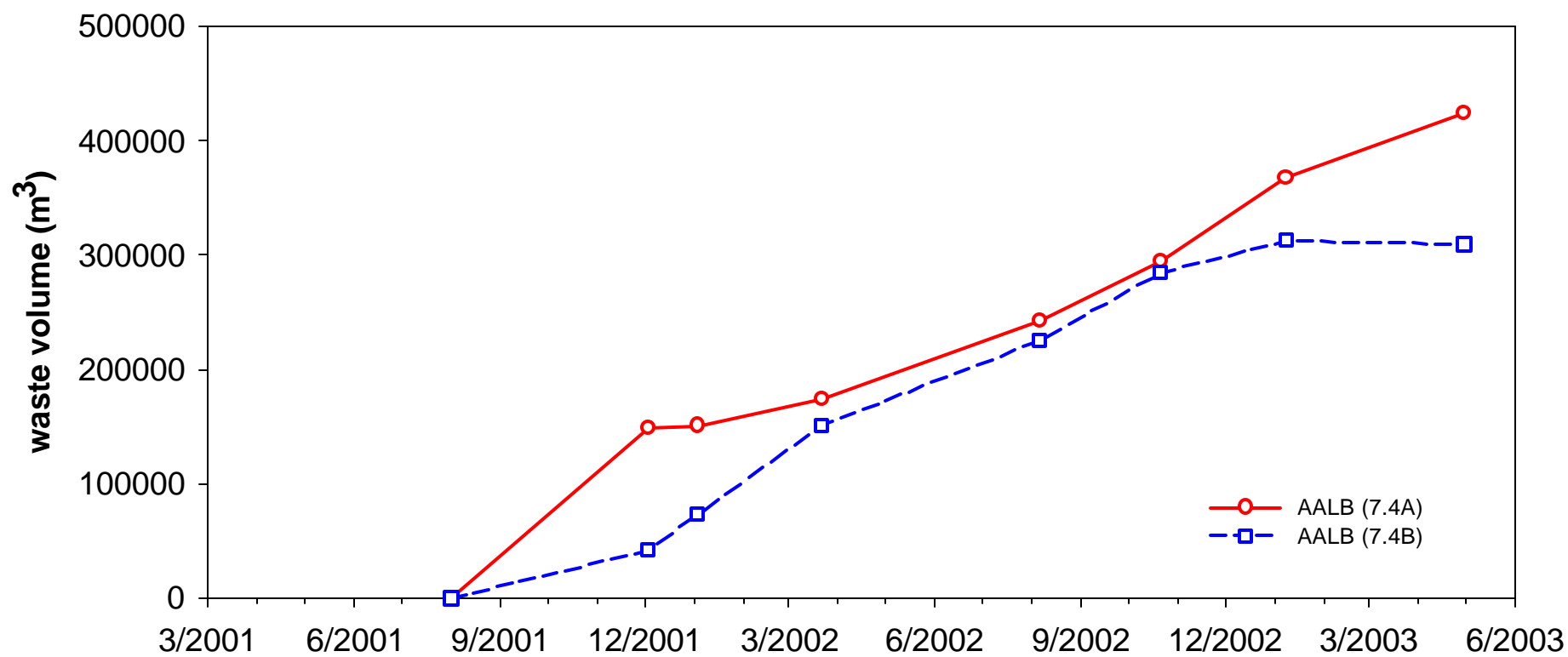


Figure 5-3. Waste Volume vs. Time for AALB Cells



Summary of Waste Settlement

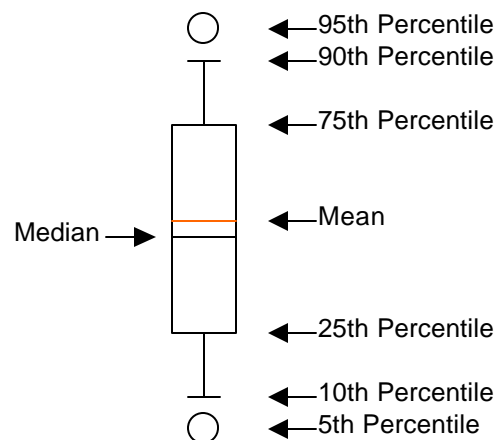
The surface elevation was measured using GPS technology for each of the Control, AALB and FLB units. The results are displayed in the form of a contour plot of total settlement for the period in the FLB, and box plots in Figures 5-4 through 5-7.

There are relatively fewer data points for Units 7.3 and 7.4 compared with Unit 5, with only three measuring events versus eight for Unit 5 FLB. In addition the significance of the GPS data relative to the objectives of this investigation for Units 7.3 and 7.4 is limited at this point owing to soil covering and active waste placement.

Unit 5 is not actively accepting waste. The last waste addition was made in 2000-2001. Relatively more of this waste was placed in the southeastern part of this Unit compared with the northern half. The GPS data for this region of Unit 5 shows a generally greater settlement (decrease in surface height) over the period, as would be expected. The box plot for FLB 5.1A also demonstrates a greater rate of settlement, decreasing with time, compared with FLB 5.2B that shows a much more consistent and lower degree of settlement.

The maximum average settlement displayed in the box plots is approximately 0.2m. When this is compared with the data spread of approximately 0.3m for that period, it can be concluded that a greater degree of settlement is required to derive meaningful results from this measurement. Longer-term elevation measurements should provide greater clarity and confidence in this parameter.

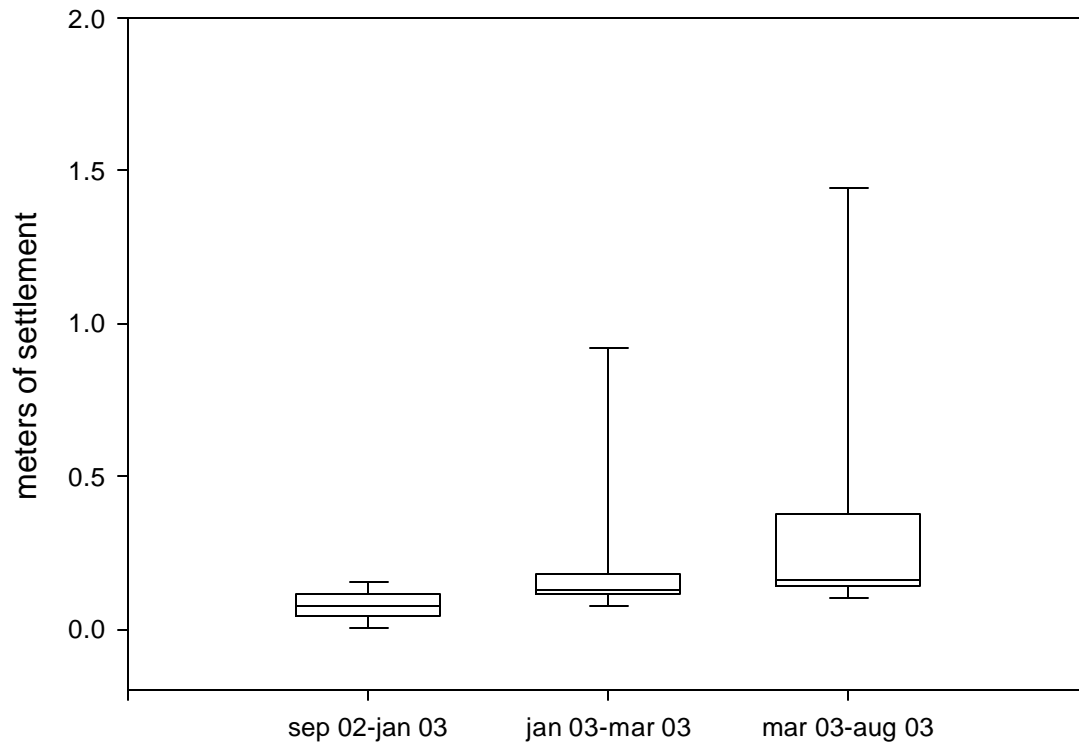
Interpretation of the Box Plot:



Insufficient data, overlap in waste age, and continued disturbance of the landfill surface may confound conclusive trends at this interim stage.

Figure 5-4. GPS Settlement Data for Control

Box Plot of Quarterly GPS Monitoring Point Settlement for Control-A Cell



Box Plot of Quarterly GPS Monitoring Point Settlement for Control-B Cell

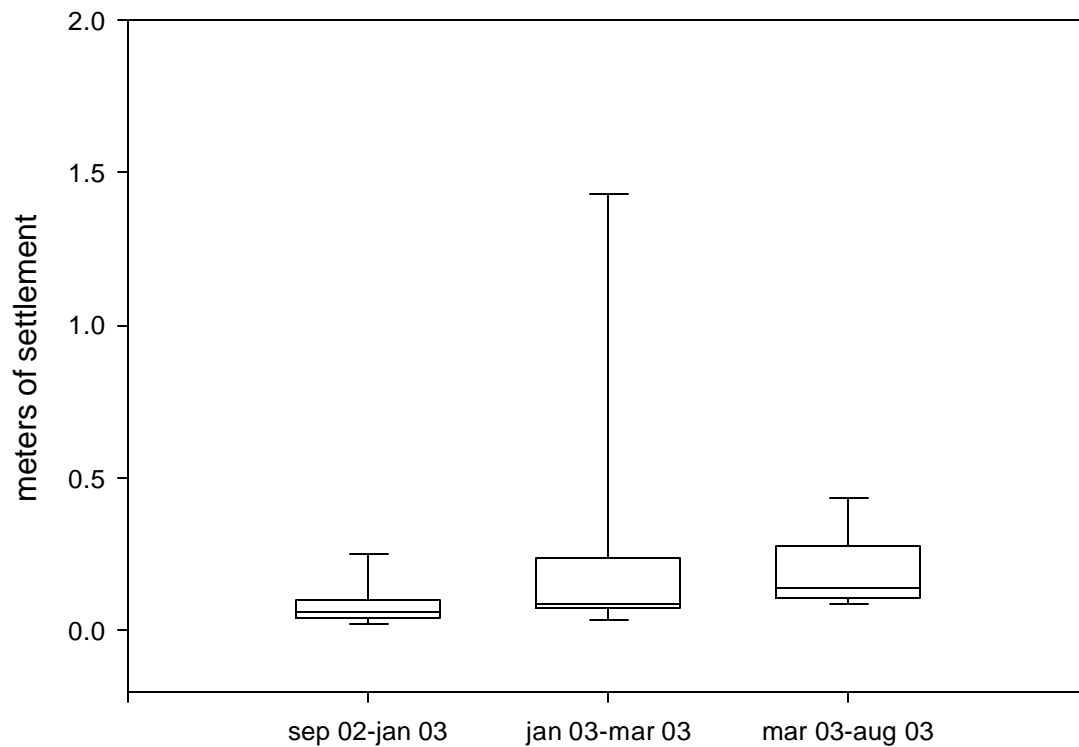
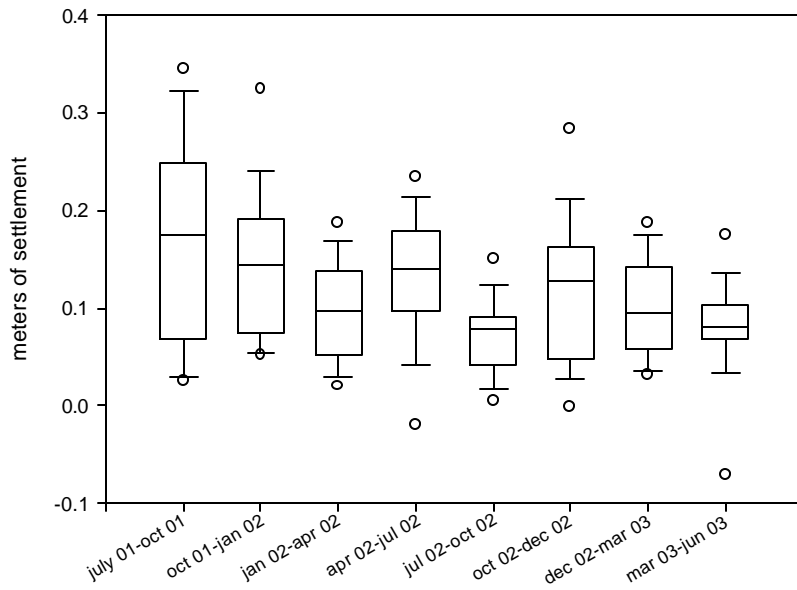
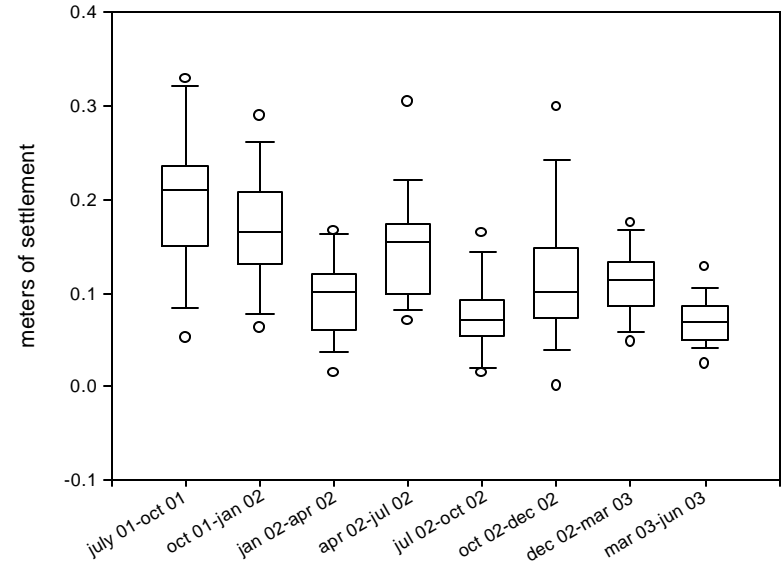


Figure 5-5. GPS Settlement Data for FLB

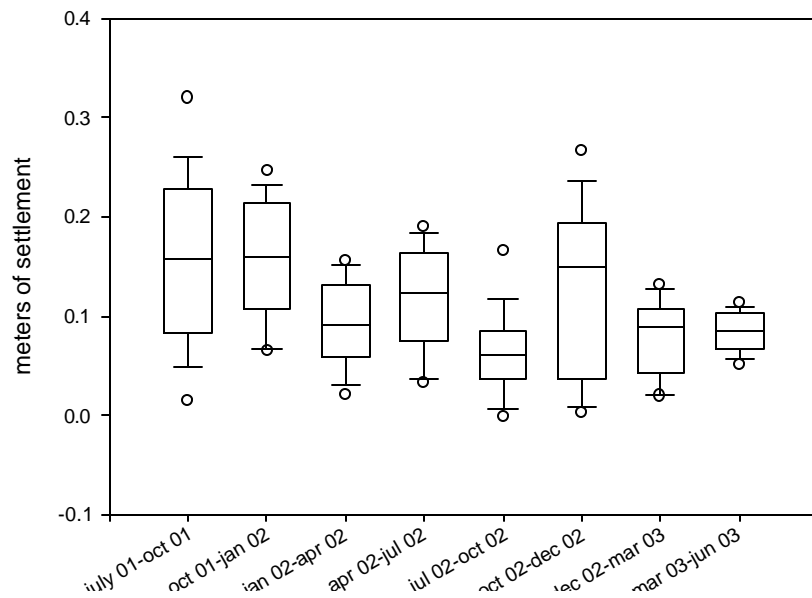
Box Plot of Quarterly GPS Settlement Monitoring Points for FLB-A



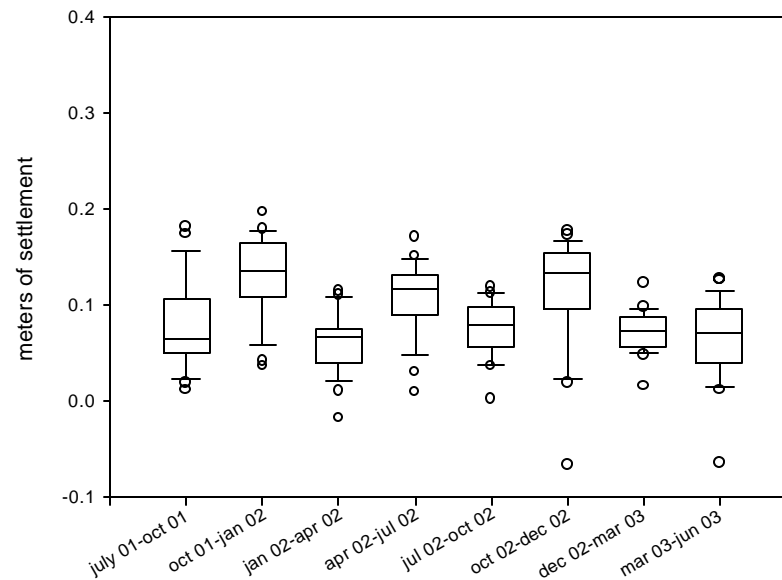
Box Plot of Quarterly GPS Settlement Monitoring Points for FLB-B



Box Plot of Quarterly GPS Settlement Monitoring Points for FLB-C



Box Plot of Quarterly GPS Settlement Monitoring Points for FLB-D



**Figure 5-6. Plan View Contour Plot of Settlement for FLB GPS Monitoring Points
(6/2001 -6/2003)**

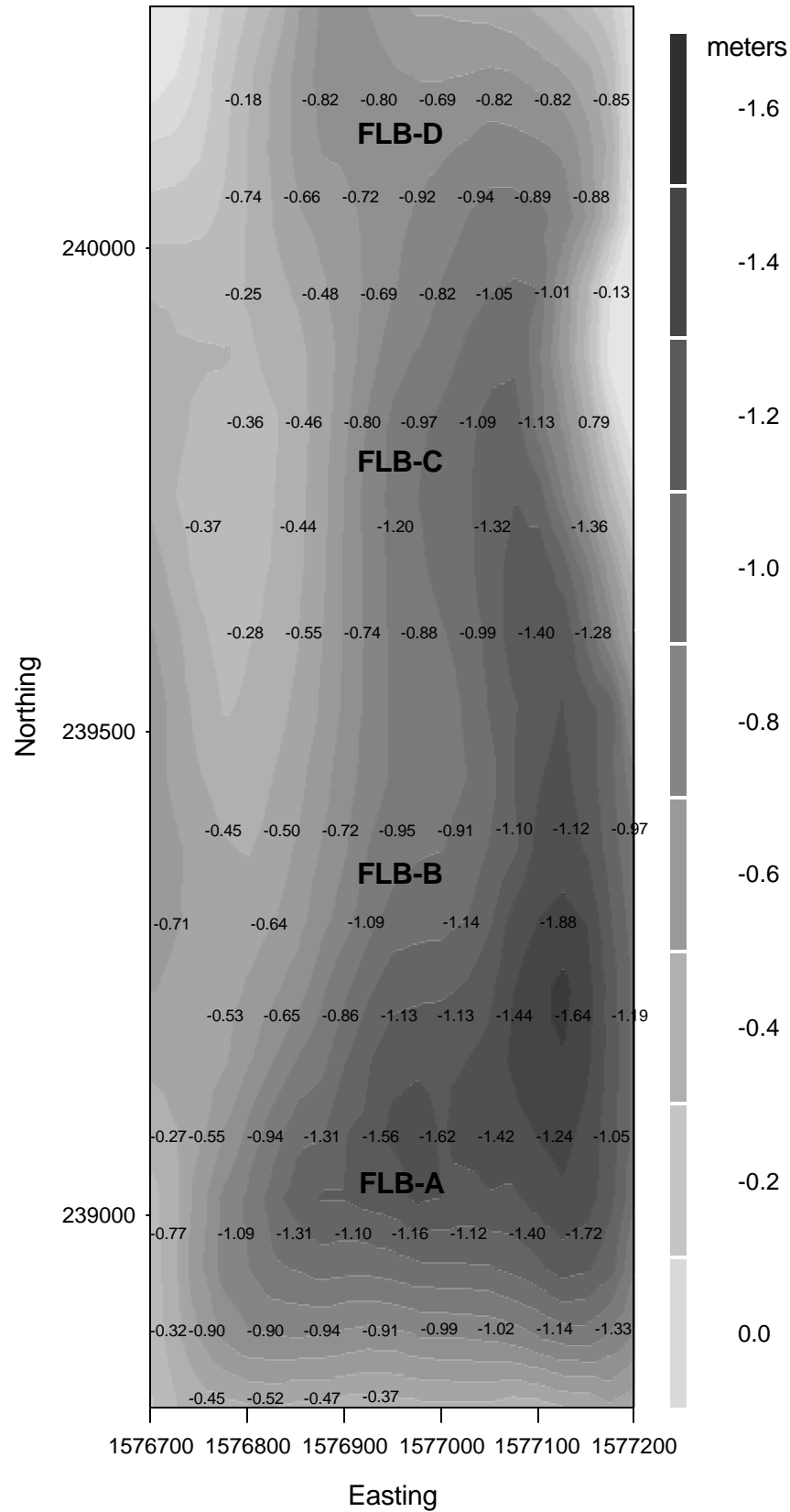
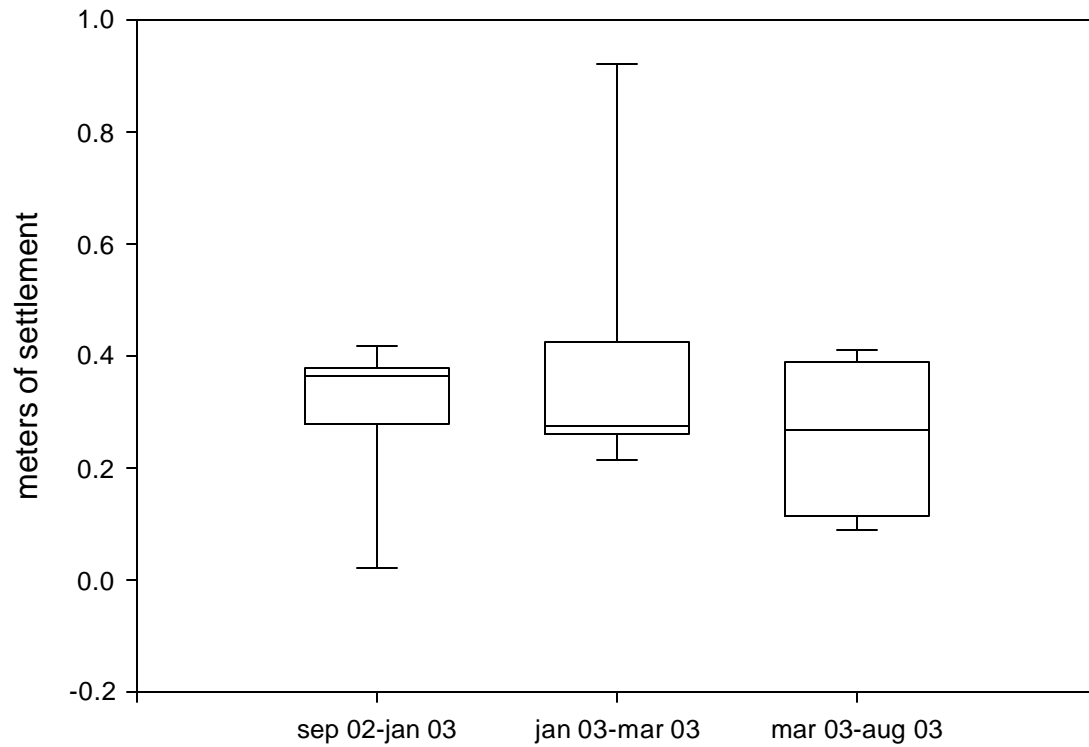
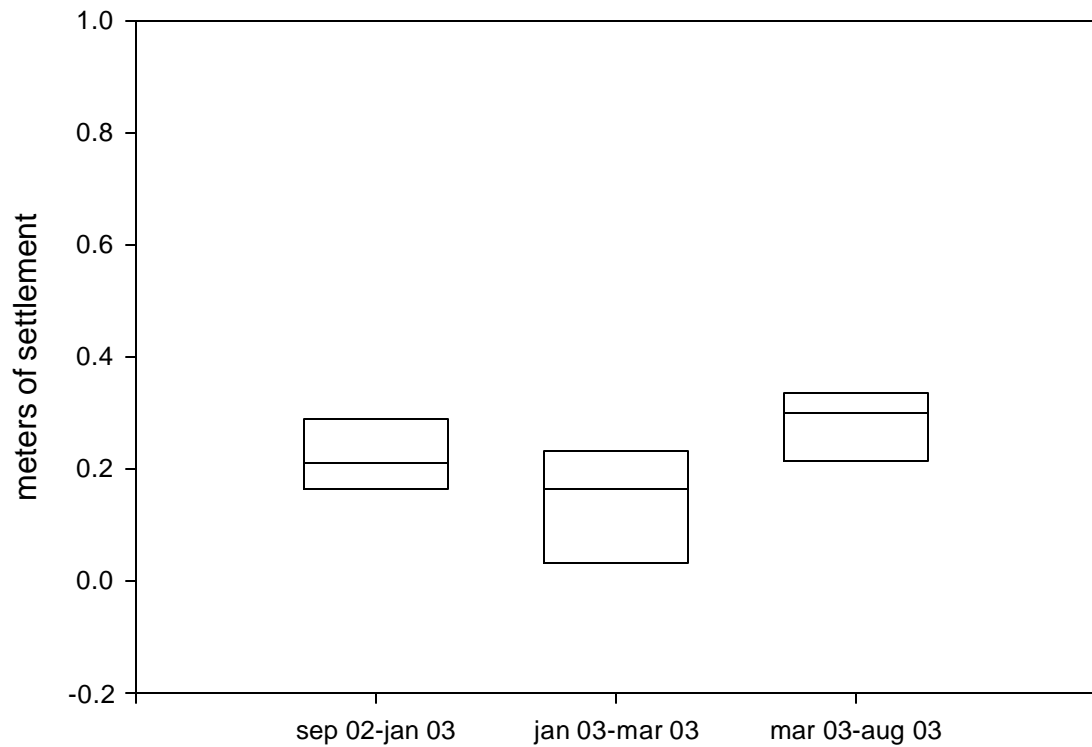


Figure 5-7. GPS Settlement Data for AALB

Box Plot of Quarterly GPS Monitoring Point Settlement for AALB-A Cell



Box Plot of Quarterly GPS Monitoring Point Settlement for AALB-B Cell



Airspace Utilization Factor (AUF)

In addition to waste settlement data, landfill operators use comparisons of calculated densities as a means to benchmark the use of the airspace created during development and filling of the landfill cells over time. Such comparisons require volume or weight data to calculate an in-place density of as-received materials. Depending on the calculation desired, these materials may be limited to simply waste, or other materials may be added in as well, such as cover materials, construction materials, moisture additions, and the like. At the Outer Loop facility, these comparisons are termed the Airspace Utilization Factor (AUF) and are calculated as follows:

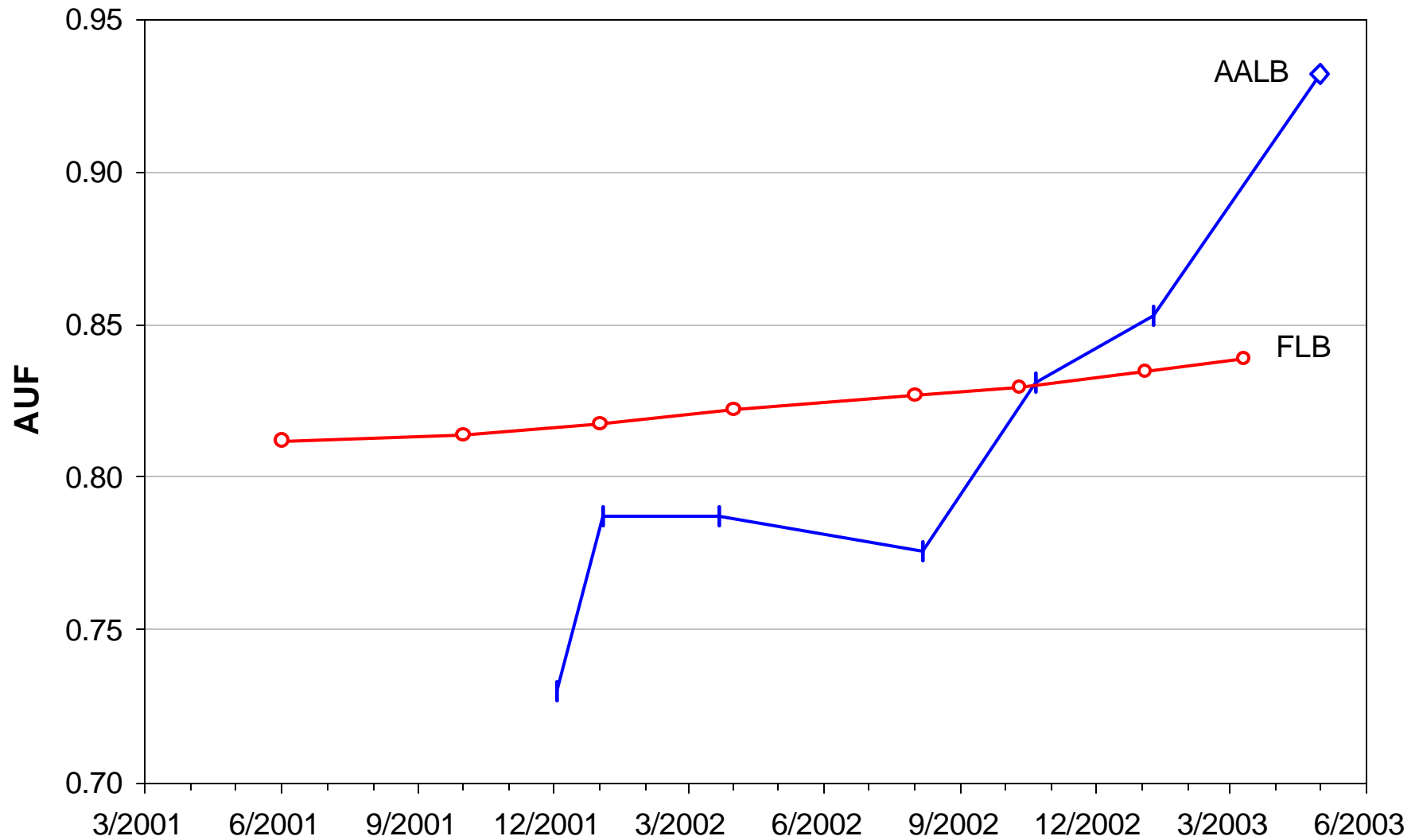
$$\text{AUF} = \frac{\text{Calculated In-Place Cell Density (weight, as received waste lbs/cell volume, yd}^3\text{)}}{\text{Target cell Density (set at 2000 lbs/cubic yard)}}$$

Where

- the weight of as-received waste materials is from scalehouse data
- the overall volume of the cell is estimated using GPS or other periodic survey methods
- Target Cell Density is a constant
- AUF is unit-less.

Figure 5-8 depicts changes in the AUF values as calculated for the FLB and AALB cells (combined) over time. Note that the AUF for the FLB is somewhat constant, rising slowly with time, as opposed to significant rises in AUF shown for the AALB. The FLB no longer receives waste materials; however, its cell volume is decreasing with time due to settlement. This accounts for the increase in the calculated in-place density. The rising plot for AALB is a function of the ongoing receipt of wastes and the likely occurrence of waste settlement.

Figure 5-8. Airspace Utilization Factor (AUF) vs. Time for FLB and AALB



LEACHATE QUALITY AND CHARACTERISTICS

As described in previous sections, leachate analyses have been taken to evaluate changes in leachate quality with respect to the program design treatments. Changes in leachate parameters are expected to broadly represent the changes in the MSW. For example, the impact of nitrified effluent applied to the FLB Landfill in Unit 5 and subsequent denitrification should impact the overall mass balance of nitrogen as the nitrogen is converted to nitrogen gas. The data collected for COD, BOD, ammonia nitrogen, nitrite-nitrogen, and nitrate-nitrogen, as well as leachate quantification (e.g., production, and head on liner), will be examined further as the project progresses. The following represent summaries of the leachate data collected to date for the Control, FLB, and AALB units.

Summary of Leachate Head on Liner

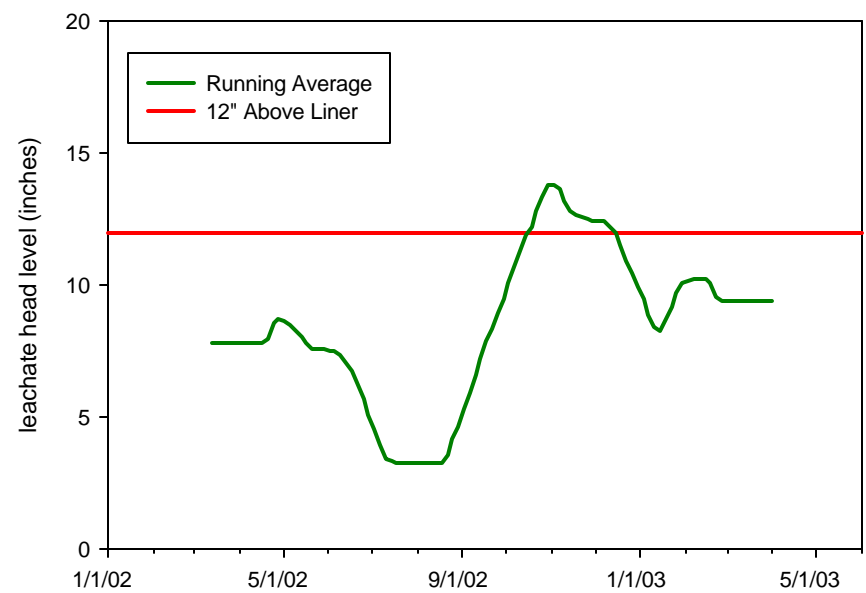
The head on liner values for the period March 2002 through March 2003 for the AALB, FLB and Control Units are presented in Figures 5-9 through 5-14. This parameter was included in this investigation to examine measured head on liner for both control and treatment cells. The data are presented in the form of scatter plots with running average lines, box plots, and histograms.

In general, mean head levels varied on an approximate seasonal basis, with significant changes occurring as a result of precipitation events. In addition, mean head levels remained at or below the permitted 12-inch level for the majority of the monitoring program. The exceptions to this were:

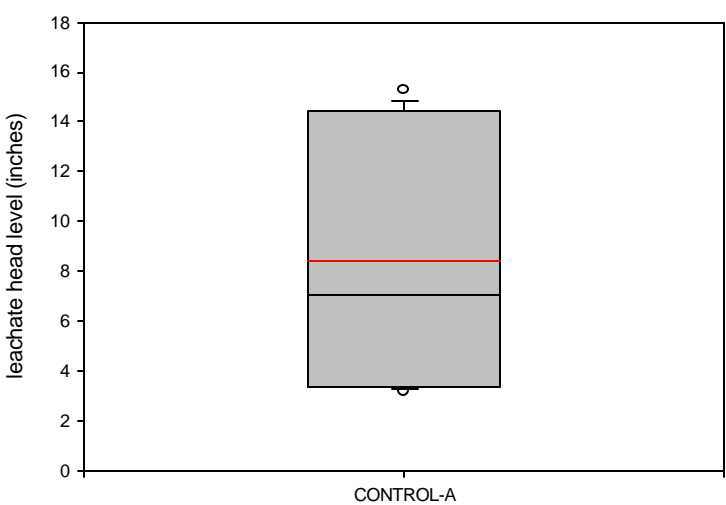
- “spikes” due to specific rainfall events;
- pumping impediments with Unit 5 relative to an apparent under capacity of the SBR; and
- pumping impediments with Unit 7 relative to an apparent under capacity of the leachate force main.

Elevated head levels attributable to precipitation events were managed with time with increased leachate pumping. With regard to the apparent under capacity of landfill bioreactor system elements, the need for increased pumping capacity was noted and examined in 2002. Design changes were determined and approved as part of the facility permit, including a planned expansion of the SBR tank and landfill cell pumping capacities. These improvements were under construction during early 2003 and are planned for completion in Autumn 2003.

Figure 5-9. Daily Mean Head Level for Control-A Cell



Box Plot of Daily Mean Head Level for Control-A Cell



Histogram of Daily Mean Head Level for Control-A Cell

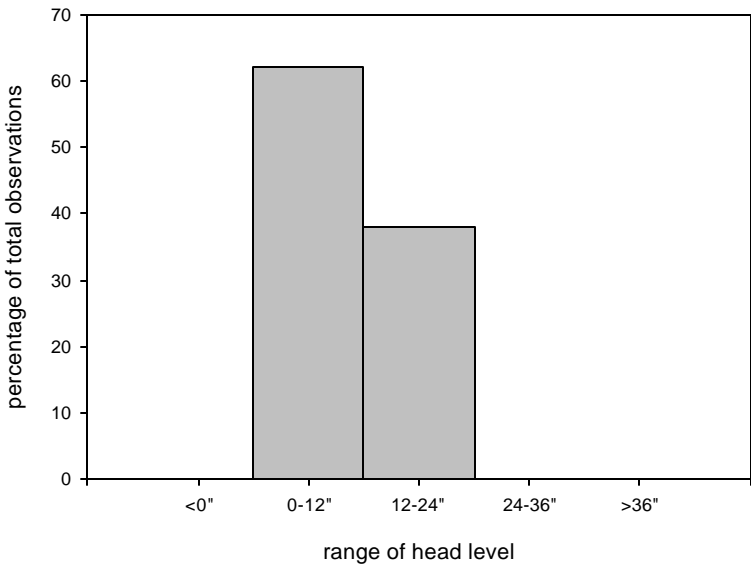
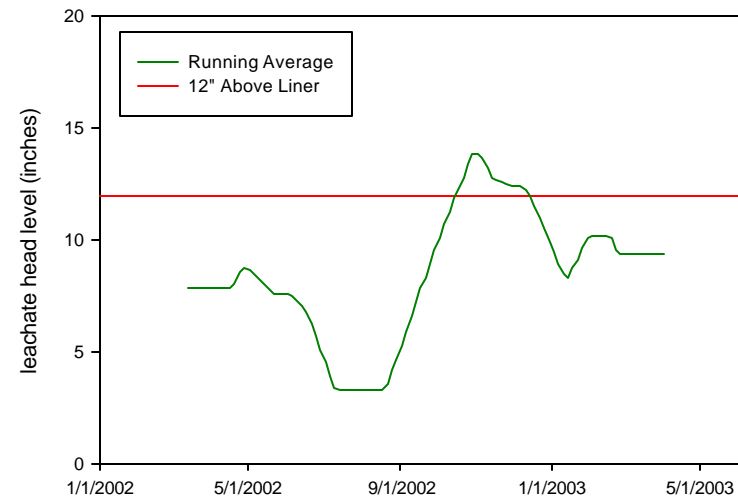
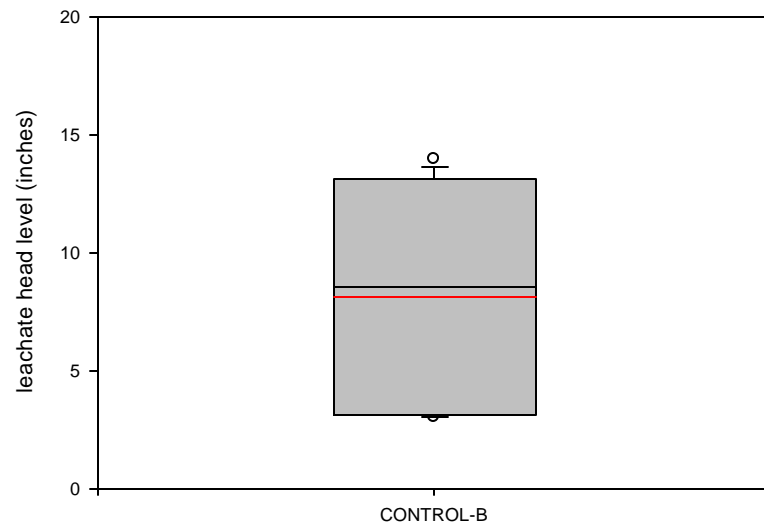


Figure 5-10. Daily Mean Head Level for Control-B Cell



Box Plot of Daily Mean Head Level for Control-B Cell



Histogram of Daily Mean Head Level for Control-B Cell

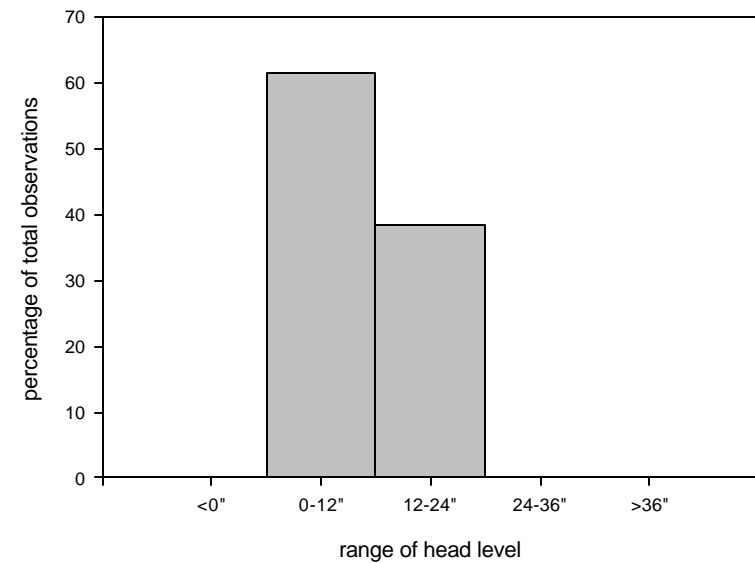
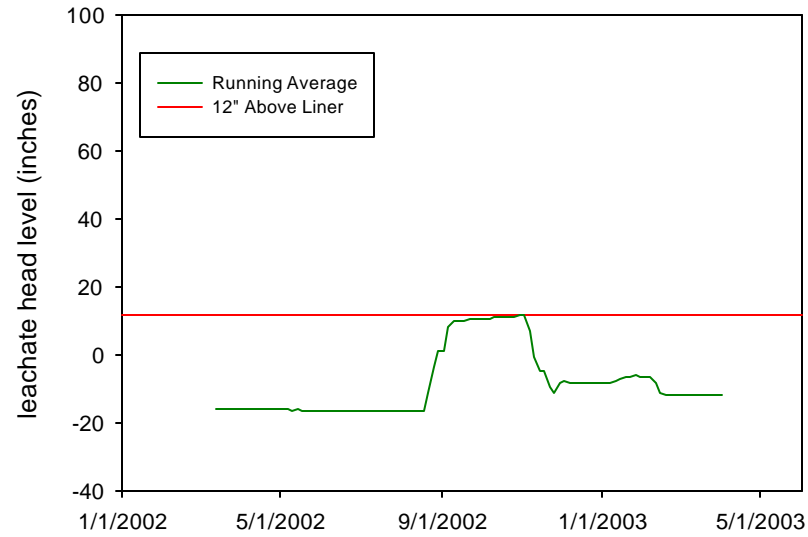
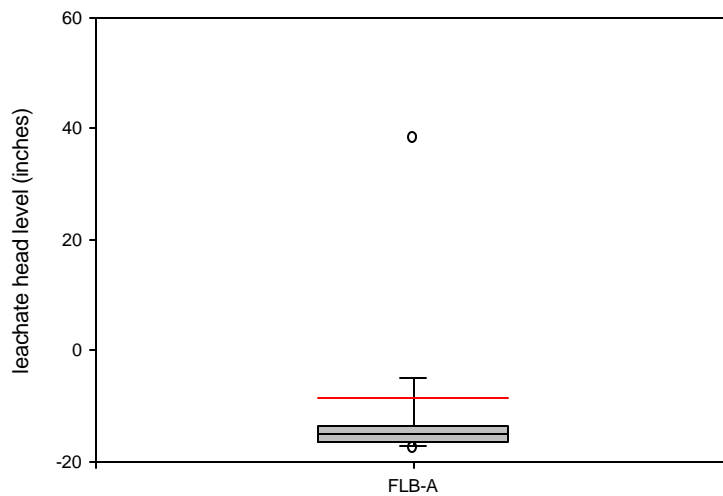


Figure 5-11. Daily Mean Head Level for FLB-A Cell



Histogram of Daily Mean Leachate Head Level for FLB-A



Histogram of Daily Mean Leachate Head Level for FLB-A Cell

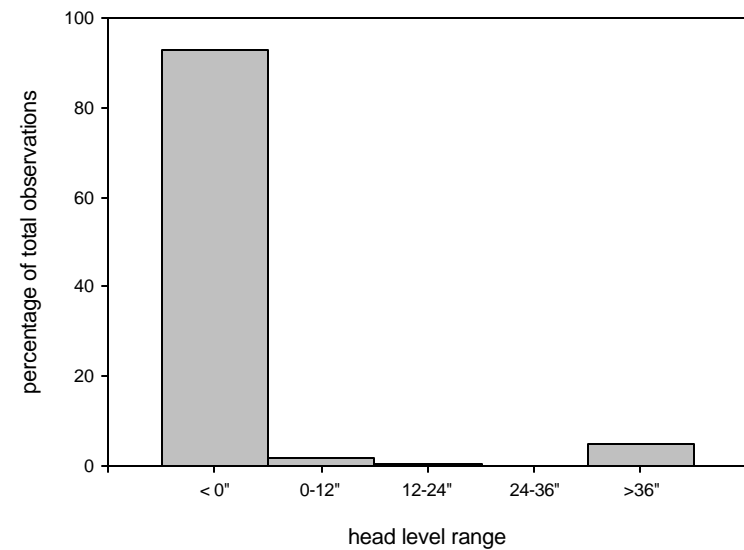
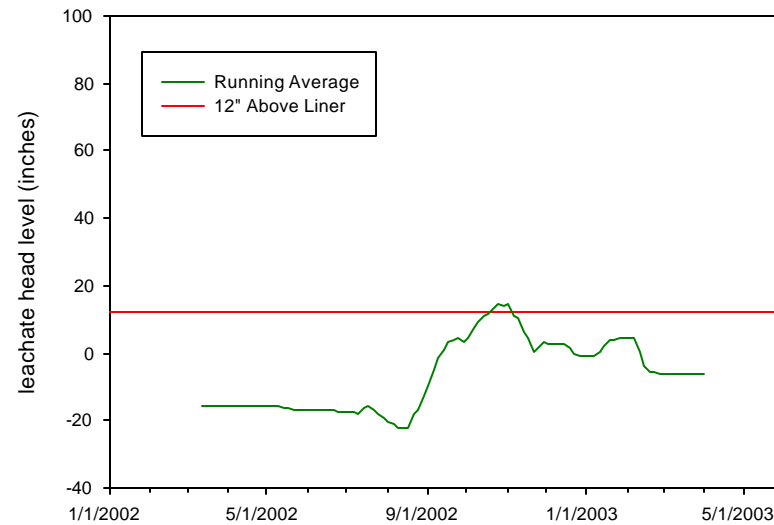
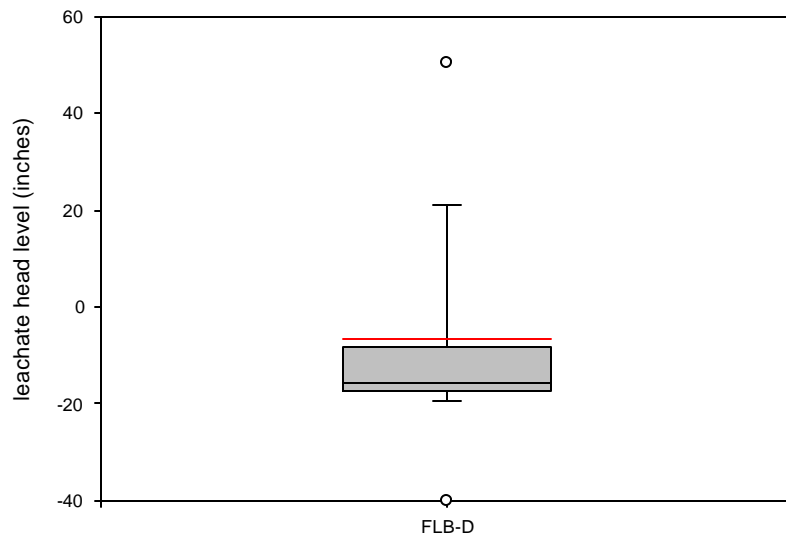


Figure 5-12. Daily Mean Head Level for FLB-D Cell



Histogram of Daily Mean Leachate Head Level for FLB-D



Histogram of Daily Mean Leachate Head Level for FLB-D Cell

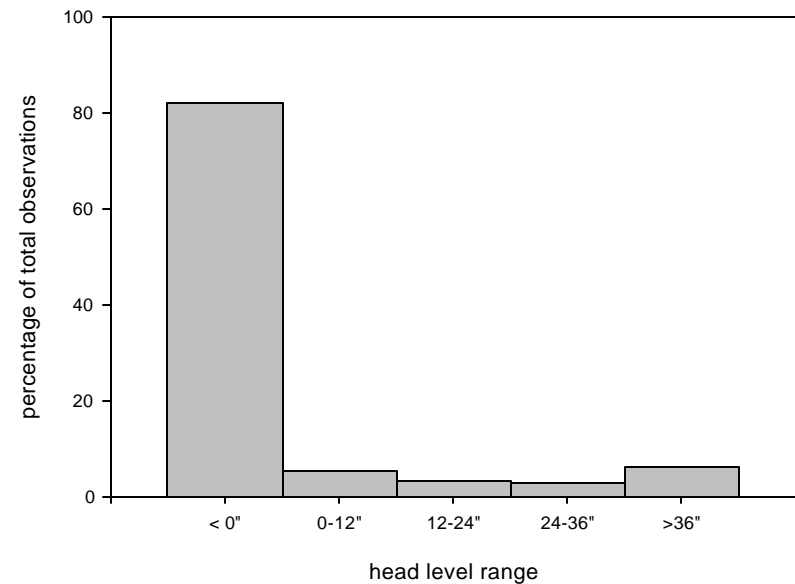
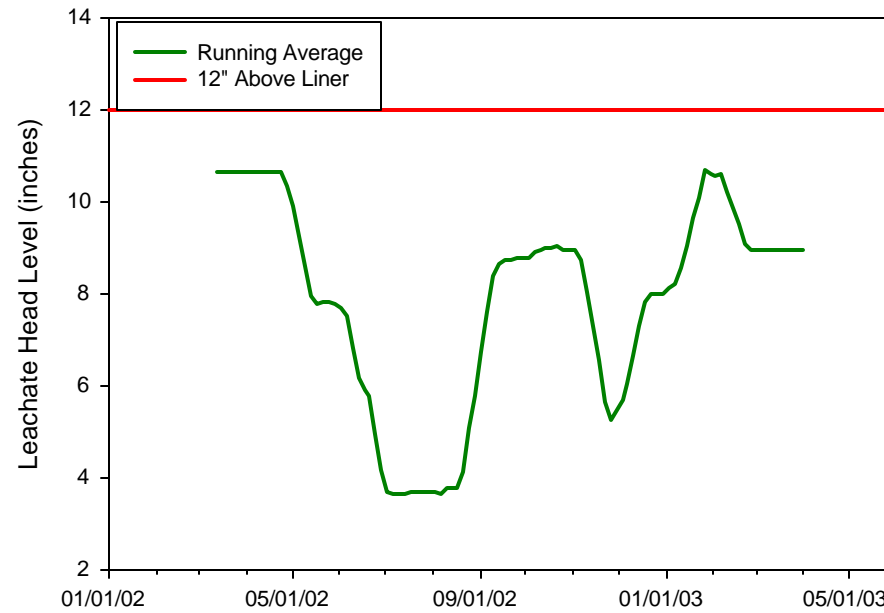
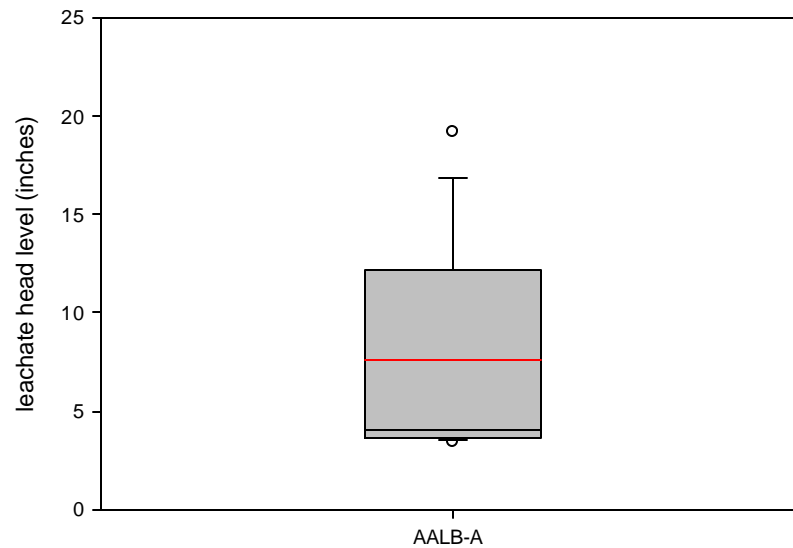


Figure 5-13. Daily Mean Head Level for AALB-A Cell



Box Plot of Daily Mean Head Level for AALB-A Cell



Histogram of Daily Mean Head Level for AALB-A Cell

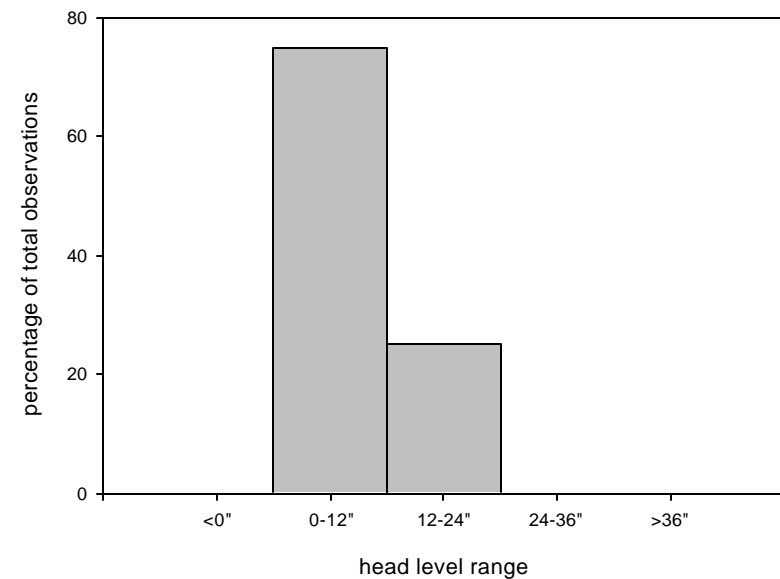
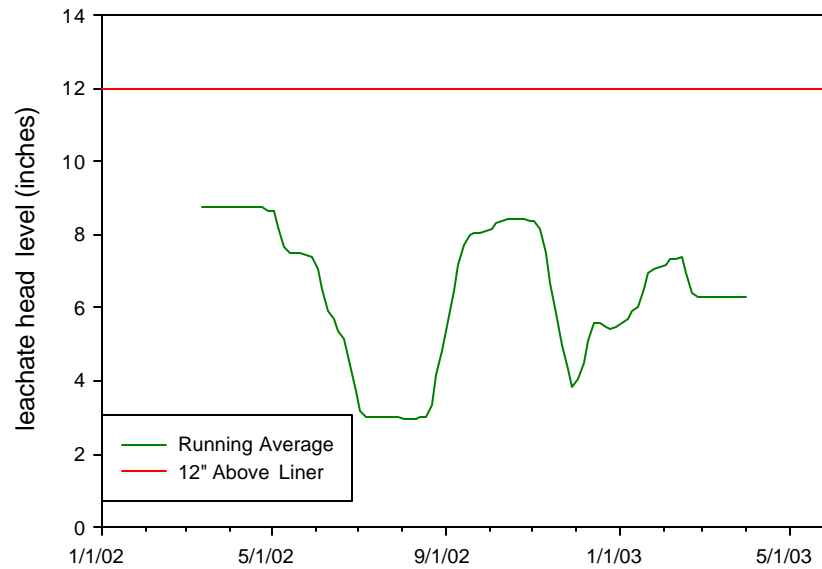
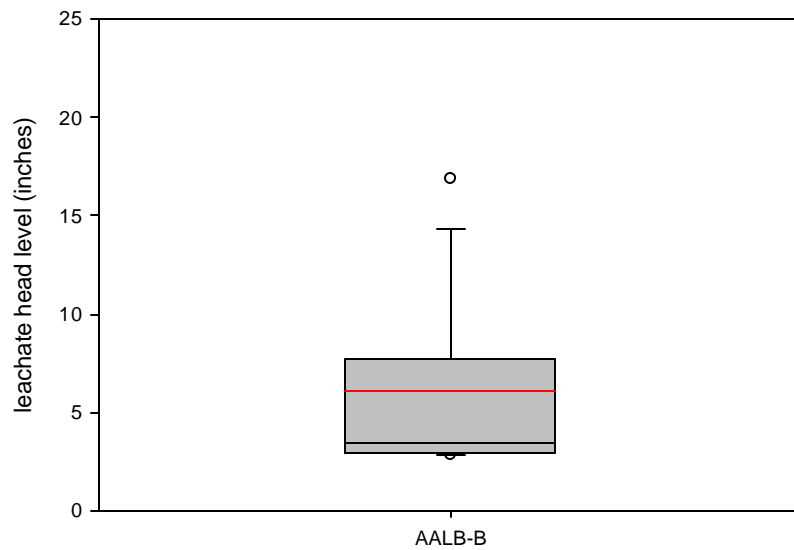


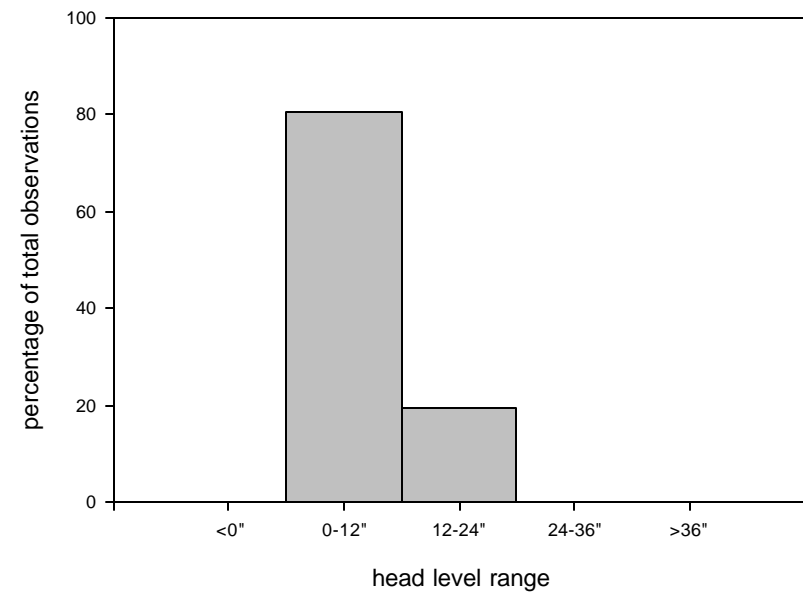
Figure 5-14. Daily Mean Head Level for AALB-B Cell



Box Plot of Daily Mean Head Level for AALB-B Cell



Histogram of Daily Mean Head Level for AALB-B Cell



Summary of Leachate Production

Cumulative leachate production is measured for each of the study cells, Control, FLB, and AALB. Measurements are taken on a continuous basis at half-hour intervals via a totalizer flow meter. The cumulative leachate production with time for each of the Units is presented in Figures 5-15 through 5-17.

The Control cells are operated as a conventional Subtitle D landfill with no additional fluids added. The rate of accumulation of leachate in Control 7.3A remained relatively steady over the period March 2002 through March 2003 averaging approximately $700\text{m}^3/\text{month}$, with a total accumulated volume over the period of $\sim 9,000\text{m}^3$. Spikes in the rate of accumulation represent significant rain events. Control 7.3B showed a much lower rate of leachate production, accumulating only approximately 400m^3 for that same period. One potential explanation for this difference is that Control A has significantly less surface area exposed than Control B. Therefore it has a much smaller precipitation catchment area relative to the footprint of that cell compared with Control B.

The FLB Unit 5 is not currently active with the last waste received in March 2001. Nitrate enriched leachate addition was initiated in March 2002 and ceased in September 2002. Leachate production in these cells is lower than that of both the AALB and the Control. Both cells 5.1A and 5.2B showed a relatively steady rate of leachate production from January 2002 until mid-September 2002, at approximately 100 and $155\text{m}^3/\text{month}$ respectively. From mid-September through October 2002 a dramatic increase in leachate production was seen with $\sim 1100\text{m}^3$ produced in 5.1A and $\sim 1400\text{m}^3$ produced in 5.2B. From November through March 2003, there was a relatively constant rate of leachate production in both cells of $240\text{m}^3/\text{month}$.

One potential explanation for the increase in leachate production from mid-September through October 2002 may be a time lag on the order of approximately six months for the additional fluids added to permeate through the landfill. These moisture quantities did not start appearing at the collection point until mid-September. The additional leachate produced at that time may have been a combination of both the additional fluids added and a consequence of heavy rainfall during the Spring period. One other explanation, or an additional part of the explanation, was that boring samples were taken in September 2002. The bore holes were back filled with permeable tire chips in order to create direct conduits for fluid to pass through the landfill and avoid perched liquids as were observed during the boring activity.

The AALB units are currently receiving waste and contain the youngest waste of all three units in the study. Additional fluids are added to this bioreactor on an ongoing basis as successive lifts of waste are placed. Both cells showed a steady rate of leachate production for the period March 2002 through March 2003. In both cells, the rate of leachate production was an order of magnitude higher than either the FLB or control at $4000\text{m}^3/\text{month}$ for 7.4A and $2500\text{m}^3/\text{month}$ for 7.4B. The total leachate accumulate over the period was 52000m^3 in 7.4A and 30000m^3 in 7.4B.

Figure 5-15. Cumulative Leachate Production vs. Time: Control Cells

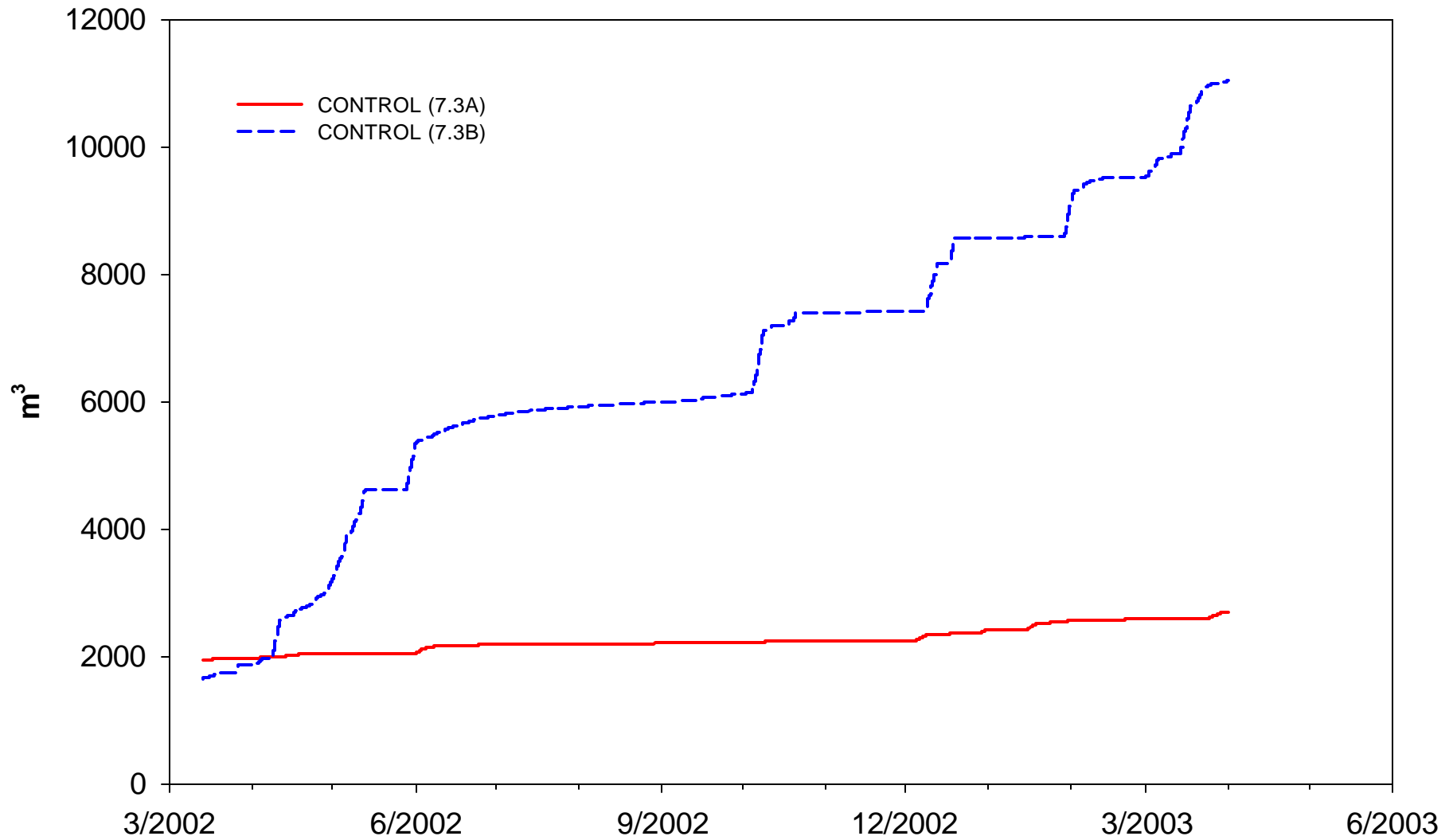


Figure 5-16. Cumulative Leachate Production vs. Time: FLB Cells

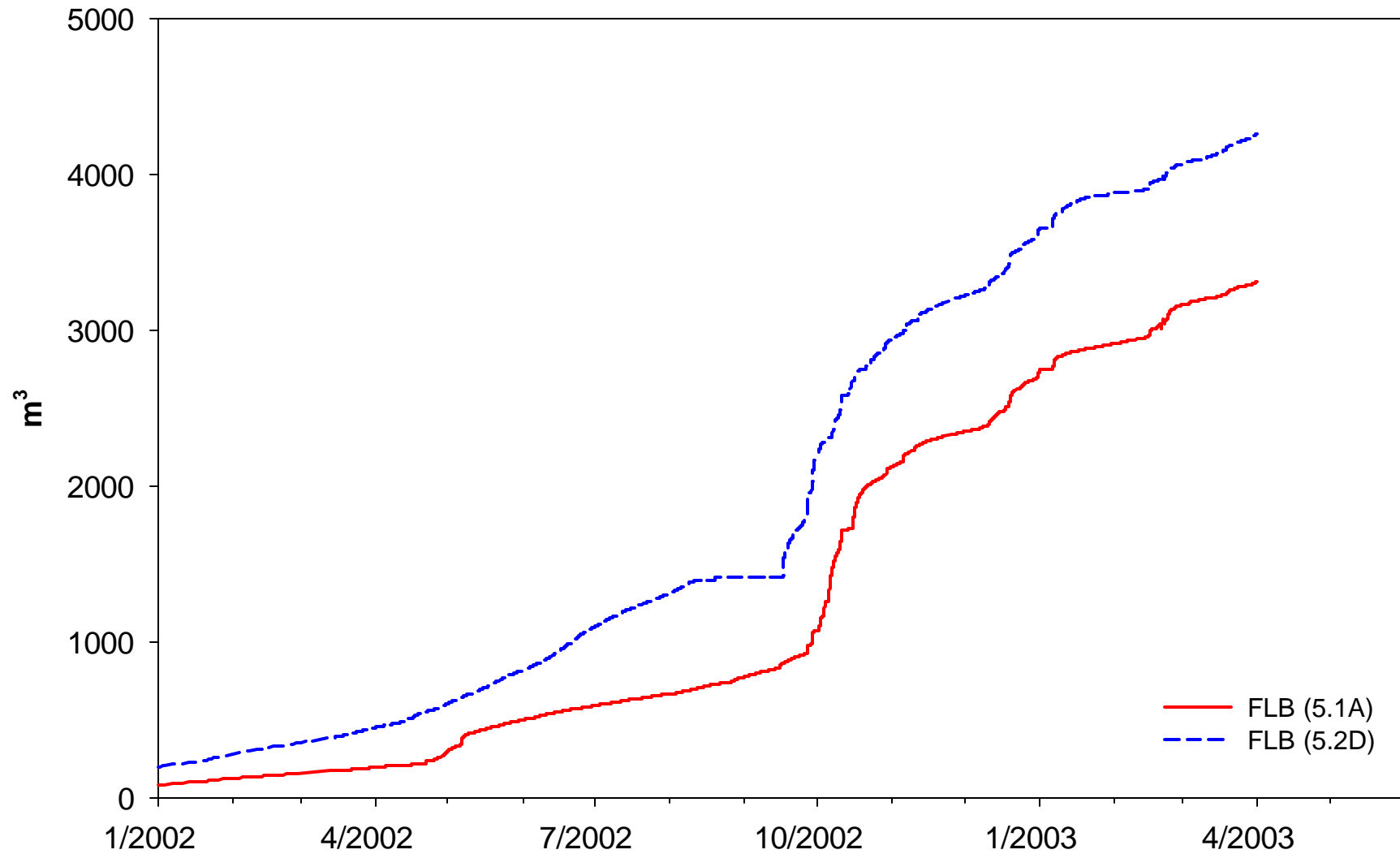
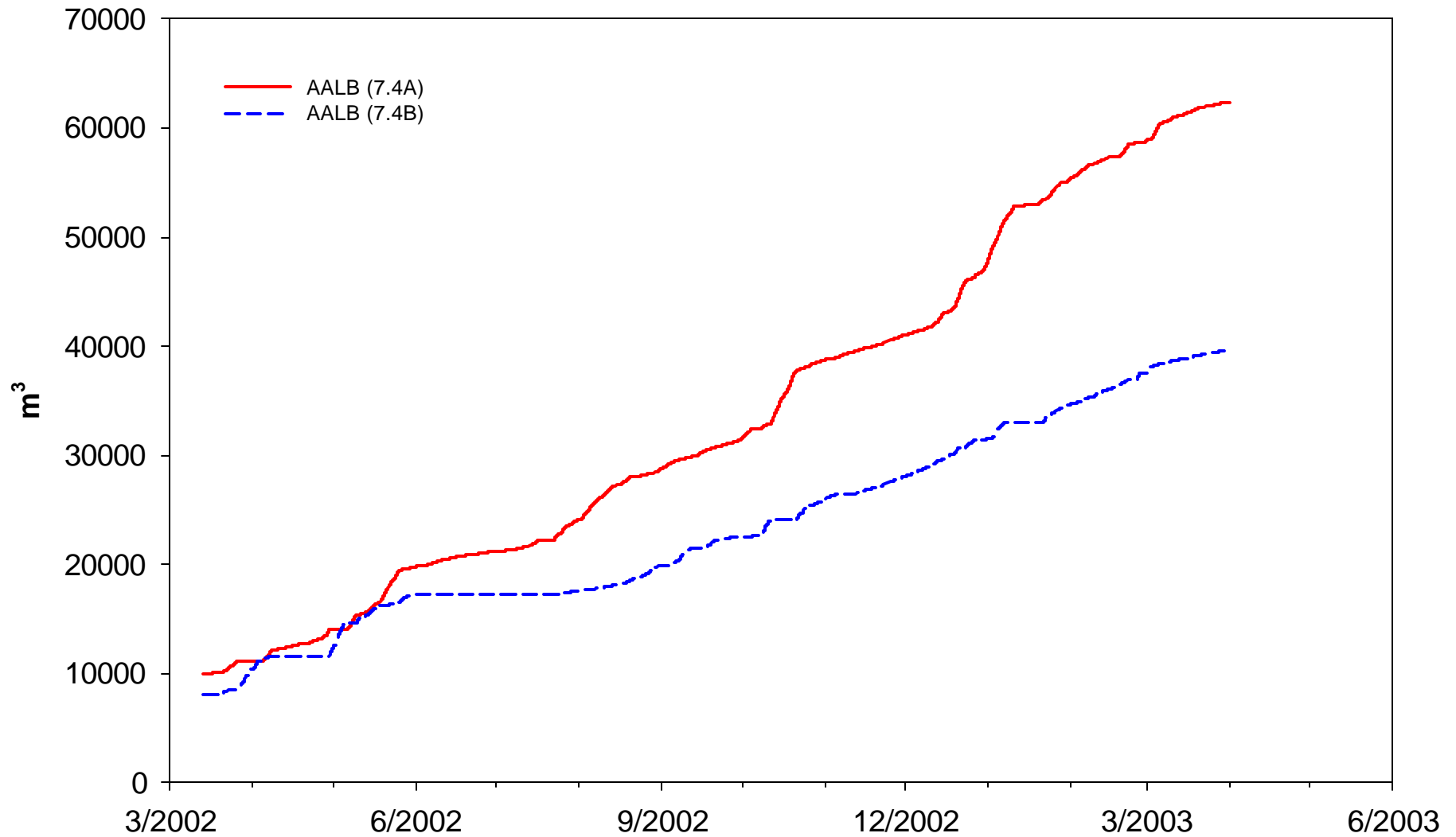


Figure 5-17. Cumulative Leachate Production vs. Time: AALB Cells



Summary of Leachate Temperature

Leachate temperature was measured for each of the study units using a Hanna Instruments Model HI 991301 pH/conductance/temperature probe. Figure 5-18 shows the temperature of leachate from each of these units. The temperature of the FLB and Control units remained relatively consistent over the period monitored, with the variation seen in both Control Cells attributable to seasonal variations. The temperature in both AALB units appear to show a slight upward trend over the period January 2001 through July 2002, before leveling off for the remaining period at a temperature closer to that recorded for the FLB unit versus the Control. Both cells in each unit display similar trends. Basic statistical parameters calculated from the data are provided below In Table 5-2.

TABLE 5-2. SUMMARY OF LEACHATE TEMPERATURE

<i>Cell</i>	<i>Minimum Temperature</i>	<i>Maximum Temperature</i>	<i>Mean Temperature</i>	<i>Standard Deviation</i>
FLB 5.1A	23.0	34.6	29.58	3.4048
FLB 5.2B	21.1	31.1	25.82	2.5980
Control 7.3A	9.5	25.3	16.24	4.9550
Control 7.3B	6.8	25.1	16.99	5.2618
AALB 7.4A	19.8	34.7	29.08	4.6699
AALB 7.4B	15.3	33.8	24.96	5.4191

Summary of Leachate pH

Leachate pH readings were collected and analyzed on a monthly basis using field electrodes, results are shown graphically in Figure 5-19. From the graph, the Control and FLB units show relatively constant pH measurements averaging a pH 7 over the June 2001 through April 2003 time period. By comparison, measurements for the AALB study unit did not begin until December 2002 and showed a greater degree of variation, ranging from a pH of below 6 in AALB-B to over 7.5. The AALB pH levels stabilized over the course of the six-month period, with current pH averaging approximately 7. Basic statistical parameters calculated from the data are provided below in Table 5-3.

TABLE 5-3. SUMMARY OF LEACHATE pH

<i>Cell</i>	<i>Minimum pH Measured</i>	<i>Maximum pH Measured</i>	<i>Mean pH</i>	<i>Standard Deviation</i>
FLB 5.1A	6.92	7.56	7.22	0.15513
FLB 5.2B	6.84	7.33	7.16	0.13203
Control 7.3A	6.38	7.31	6.83	0.29601
Control 7.3B	6.14	7.20	6.75	0.33671
AALB 7.4A	6.31	7.40	7.07	0.27369
AALB 7.4B	5.89	7.57	6.96	0.50964

Summary of Leachate COD

The COD concentration from the Control units and the AALB units are variable. Concentrations range from under 100 mg/l to approximately 6,000 mg/l, in Control 7.3B, and approximately 1,000 to 30,000 mg/l in the AALB 7.4A. These ranges are comparable with those of the duplicate cells in those units. This variation in the COD concentration corresponds to the addition or presence of newer waste to the landfill units. COD measurements in the FLB study unit remain more constant, with the exception of a sharp dip in COD concentrations recorded for FLB 5.2 in March 2002. COD measurements following the March 2002 reading in FLB 5.2 stabilize and average approximately 1000 mg/l for the remaining period of measurement, as represented graphically in Figure 5-20. Basic statistical parameters calculated from the data are provided below in Table 5-4.

TABLE 5-4. SUMMARY OF LEACHATE COD

<i>Cell</i>	<i>Minimum COD Measured</i>	<i>Maximum COD Measured</i>	<i>Mean COD</i>	<i>Standard Deviation</i>
FLB 5.1A	882.0	2620	1848.0	449.1
FLB 5.2B	114.0	3560	1366.0	640.7
Control 7.3A	114.0	3170	667.2	721.0
Control 7.3B	60.3	5720	963.8	1297.2
AALB 7.4A	916.0	30900	5282.0	7488.5
AALB 7.4B	1840.0	26000	7222.0	7039.3

Summary of Leachate BOD

Sampling for BOD began in June 2001 for both the Control and FLB units. Sampling for BOD in the AALB began in December 2001. Results of the BOD analysis are shown graphically in Figure 5-21. Basic statistical parameters calculated from the data are also provided below in Table 5-5.

BOD levels showed considerable variation early in the sampling process in the Control and AALB units. Levels in the Control showed values ranging from below 50 mg/l to greater than 5,000 mg/l in the first 13 months of sampling. The AALB indicated similar values, but has continued to show varied readings through the most recently reported sampling events. BOD results for the FLB show less varied results with values ranging from approximately 100 mg/l to 1,000 mg/l.

TABLE 5-5. SUMMARY OF LEACHATE BOD

<i>Cell</i>	<i>Minimum BOD Measured</i>	<i>Maximum BOD Measured</i>	<i>Mean BOD</i>	<i>Standard Deviation</i>
FLB 5.1A	32.9	1060	189.0	228.7
FLB 5.2B	24.9	783	156.0	185.7
Control 7.3A	14.6	1820	155.6	395.4
Control 7.3B	9.2	31400	1784.0	6805.0
AALB 7.4A	20.0	15000	1967.0	3427.1
AALB 7.4B	142.0	54400	6233.0	12546.6

Figure 5-18. Leachate Temperature vs. Time

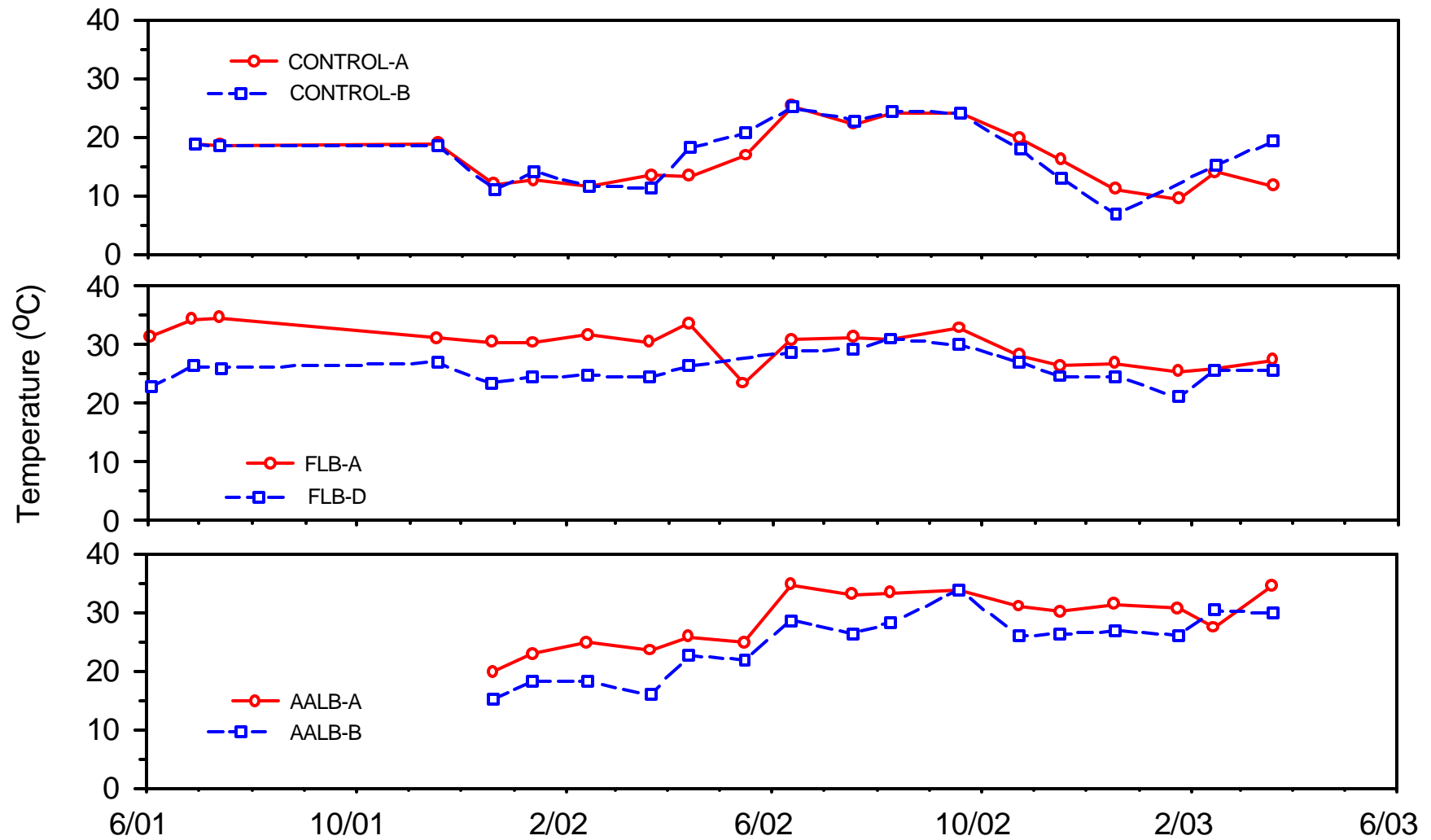


Figure 5-19. Leachate pH vs. Time

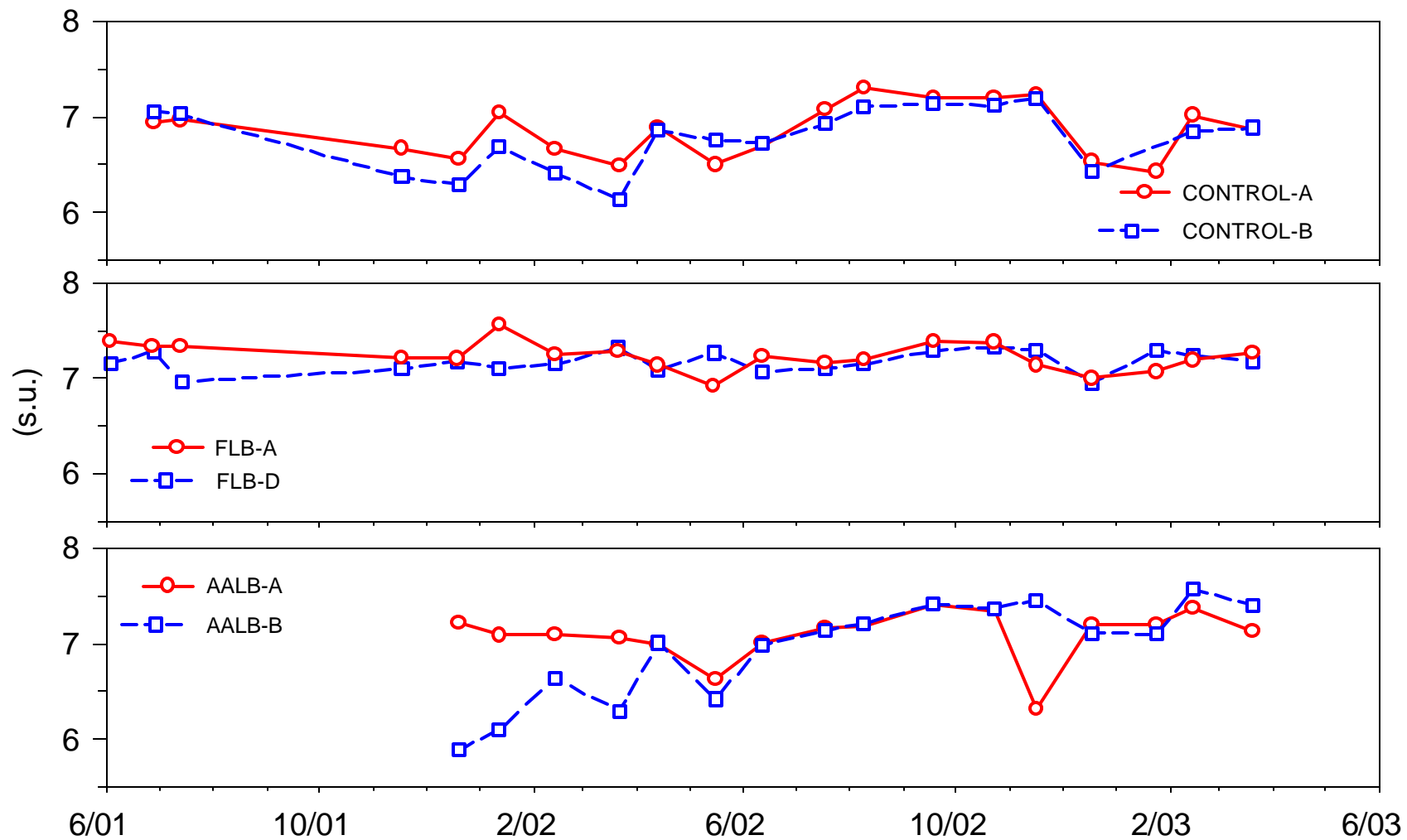


Figure 5-20. Leachate COD vs. Time

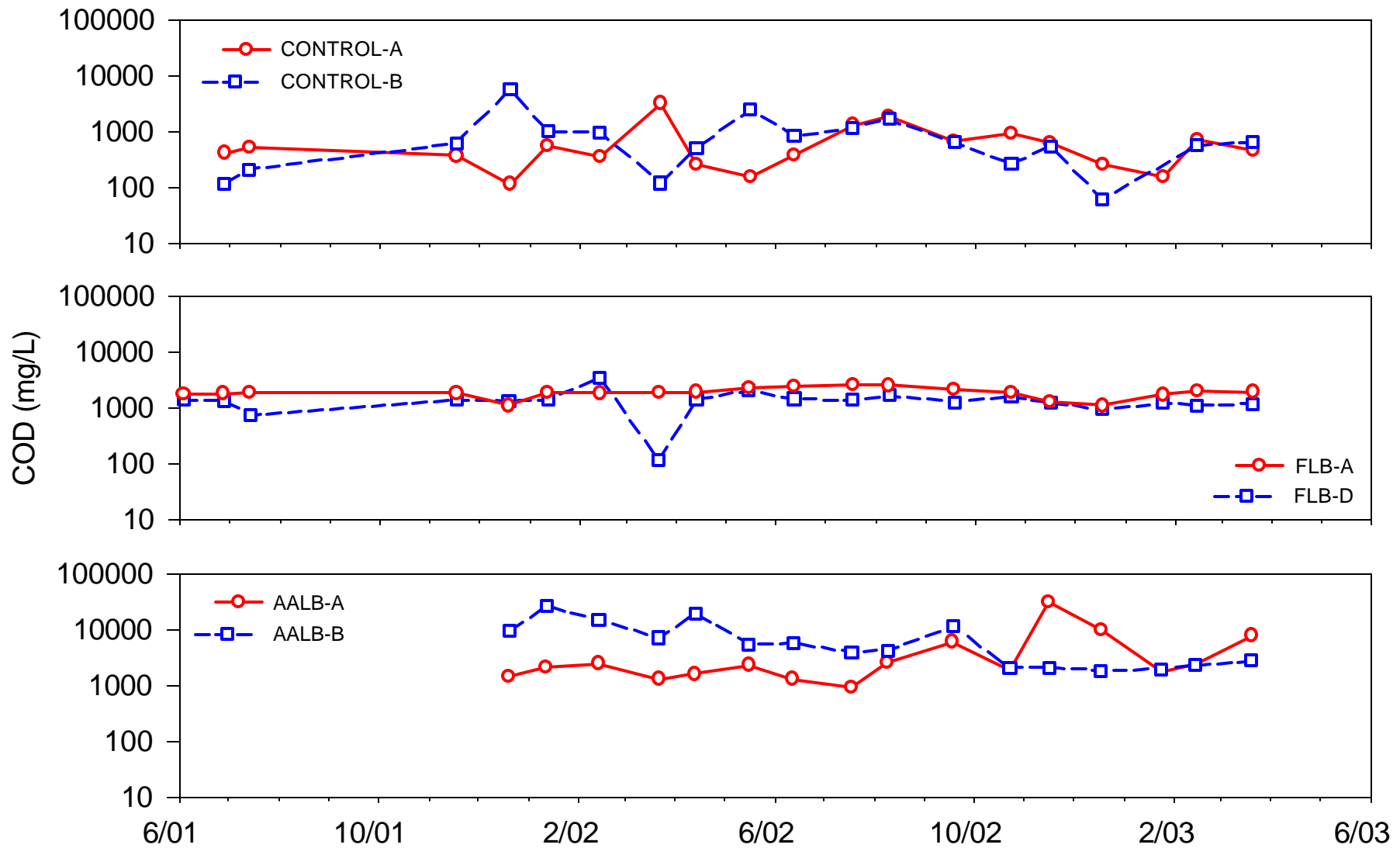
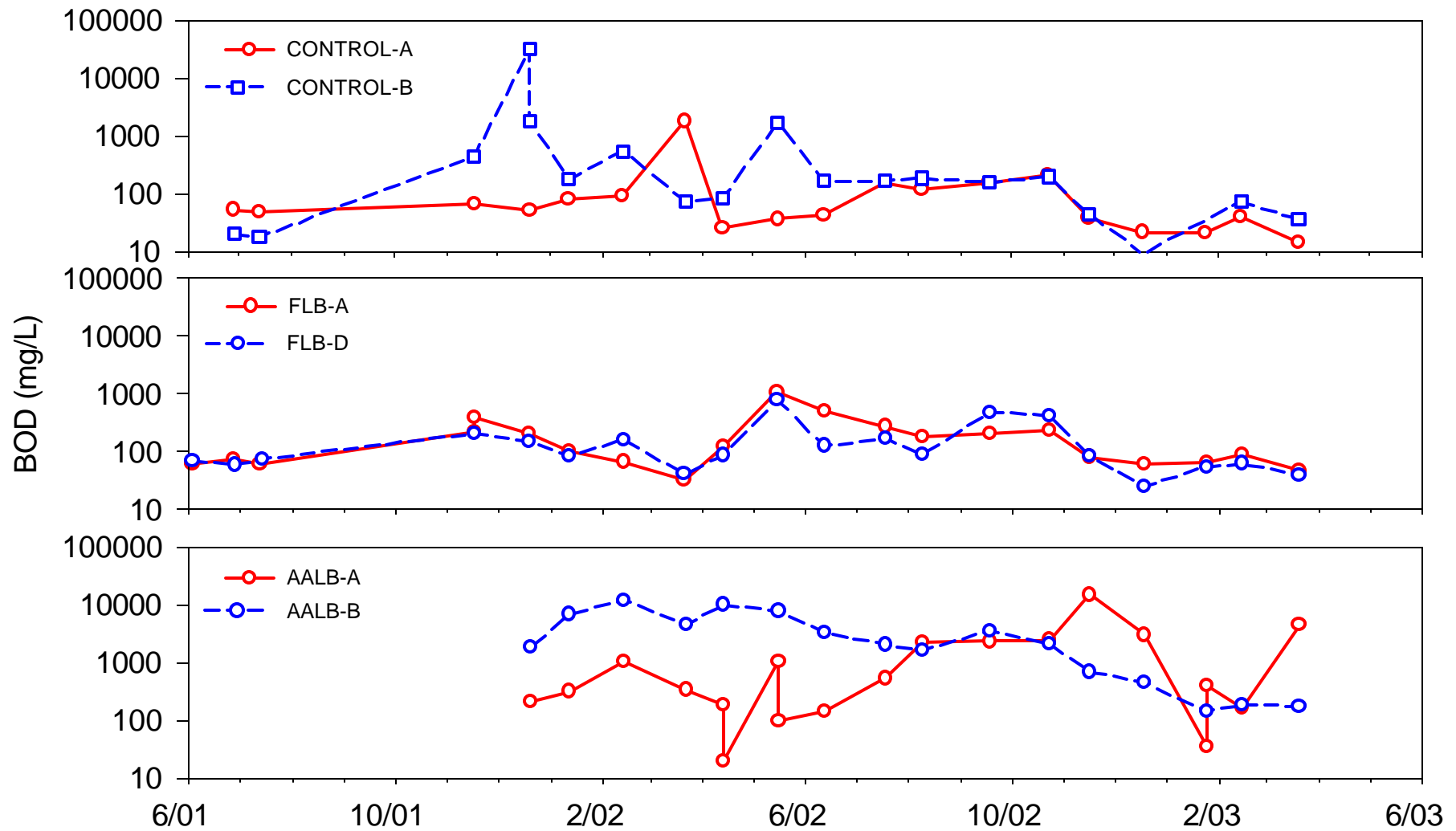


Figure 5-21. Leachate BOD vs. Time



Summary of Leachate Conductance

The leachate conductance for each of the three study units is shown graphically in Figure 5-22. Conductance was measured on a monthly basis using a field electrode.

Conductance levels in the FLB and AALB were considerably higher than those levels found in the Control unit. Results in the FLB ranged from approximately 9,000 umhos/cm to 15,000 umhos/cm. Results for the AALB showed readings that varied between 6,000 umhos/cm to nearly 17,000 umhos/cm. Levels for the Control unit indicated relatively stable reading that averaged 3,000 umhos/cm, with a spike in the September 2002 sampling of 12,000 umhos/cm, levels returned to the 3,000 umhos/cm range following this sampling event.

Summary of Leachate Ammonia-Nitrogen (NH₃-N) Levels

Ammonia Nitrogen Levels in leachate were analyzed in samples taken on a monthly basis. Results of Ammonia Nitrogen levels in leachate are shown graphically in Figure 5-23. Basic statistical parameters calculated from the data are provided below in Table 5-6.

Sampling began in June 2001 for the Control and FLB units and in December 2001 for the AALB unit. Samples for all three of the study units show relatively consistent results averaging approximately 500 mg/l in the Control and AALB units. The FLB unit showed a higher average of approximately 1000 mg/l.

TABLE 5-6. SUMMARY OF LEACHATE AMMONIA-NITROGEN LEVELS

<i>Cell</i>	<i>Min [NH₄-N] Measured</i>	<i>Max [NH₄-N] Measured</i>	<i>Mean [NH₄-N]</i>	<i>Standard Deviation</i>
FLB 5.1A	551	19200	2445	4410
FLB 5.2B	432	7010	1291	1393
Control 7.3A	67	1420	460	432
Control 7.3B	49	1410	376	406
AALB 7.4A	162	2720	922	653
AALB 7.4B	97	1540	921	463

Summary of Leachate Nitrate-Nitrogen (NO₃-N) Levels

Nitrate-Nitrogen levels (NO₃-N) were analyzed from samples taken on a monthly basis in the laboratory using EPA Method 353.2. Sample results for the three study units are displayed in Figure 5-24. Basic statistical parameters calculated from the data are provided below in Table 5-7.

Both the Control and FLB units showed a relatively stable nitrate level over the period 6/01 through 4/03, typically in the 0.01 to 0.1mg/L range. The AALB unit showed greater variability over the period of measurement, 12/01 through 4/03, in both A and B cells. AALB A showed concentrations typically in the same, to one order of magnitude higher, range as the Control and FLB units. AALB B, however, showed overall higher nitrate levels, typically one order of magnitude but reaching levels of >10mg/L.

TABLE 5-7. SUMMARY OF LEACHATE NITRATE-NITROGEN

<i>Cell</i>	<i>Min [NO₃-N] Measured</i>	<i>Max [NO₃-N] Measured</i>	<i>Mean [NO₃-N]</i>	<i>Standard Deviation</i>
FLB 5.1A	0.02	0.13	0.06	0.04
FLB 5.2B	0.02	0.20	0.04	0.05
Control 7.3A	0.02	0.20	0.05	0.06
Control 7.3B	0.02	0.26	0.05	0.06
AALB 7.4A	0.02	1.70	0.22	0.40
AALB 7.4B	0.02	26.50	2.31	6.38

Summary of Leachate Nitrite-Nitrogen (NO₂-N) Levels

Leachate nitrite-nitrogen (NO₂-N) measurements are taken on a monthly basis for all three of the study units, plots showing the concentrations vs. time are shown in Figure 5-25. Sample collection started in 6/01 for the FLB and Control units, and 12/01 for the AALB unit. Basic statistical parameters calculated from the data are provided below in Table 5-8.

Trends for nitrite-nitrogen have remained relatively steady for the FLB and Control units with measurements averaging in both cases approximately 0.1mg/L (typical range 0.05 – 0.5mg/L). The measurements for the AALB A cell were comparable with the Control and FLB. AALB B showed greater fluctuation with measurements varying between 0.1 to 10mg/l in the first eight to nine months of measurement. AALB B nitrite levels showed indications of stabilization around August 2002, with readings averaging 0.1 mg/l.

TABLE 5-8. SUMMARY OF NITRITE-NITROGEN

<i>Cell</i>	<i>Min [NO₂-N] Measured</i>	<i>Max [NO₂-N] Measured</i>	<i>Mean [NO₂-N]</i>	<i>Standard Deviation</i>
FLB 5.1A	0.02	0.28	0.08	0.07
FLB 5.2B	0.02	0.24	0.06	0.06
Control 7.3A	0.02	0.28	0.06	0.07
Control 7.3B	0.02	2.00	0.19	0.45
AALB 7.4A	0.05	0.65	0.24	0.18
AALB 7.4B	0.09	10.70	1.30	2.78

Figure 5-22. Leachate Conductance vs. Time

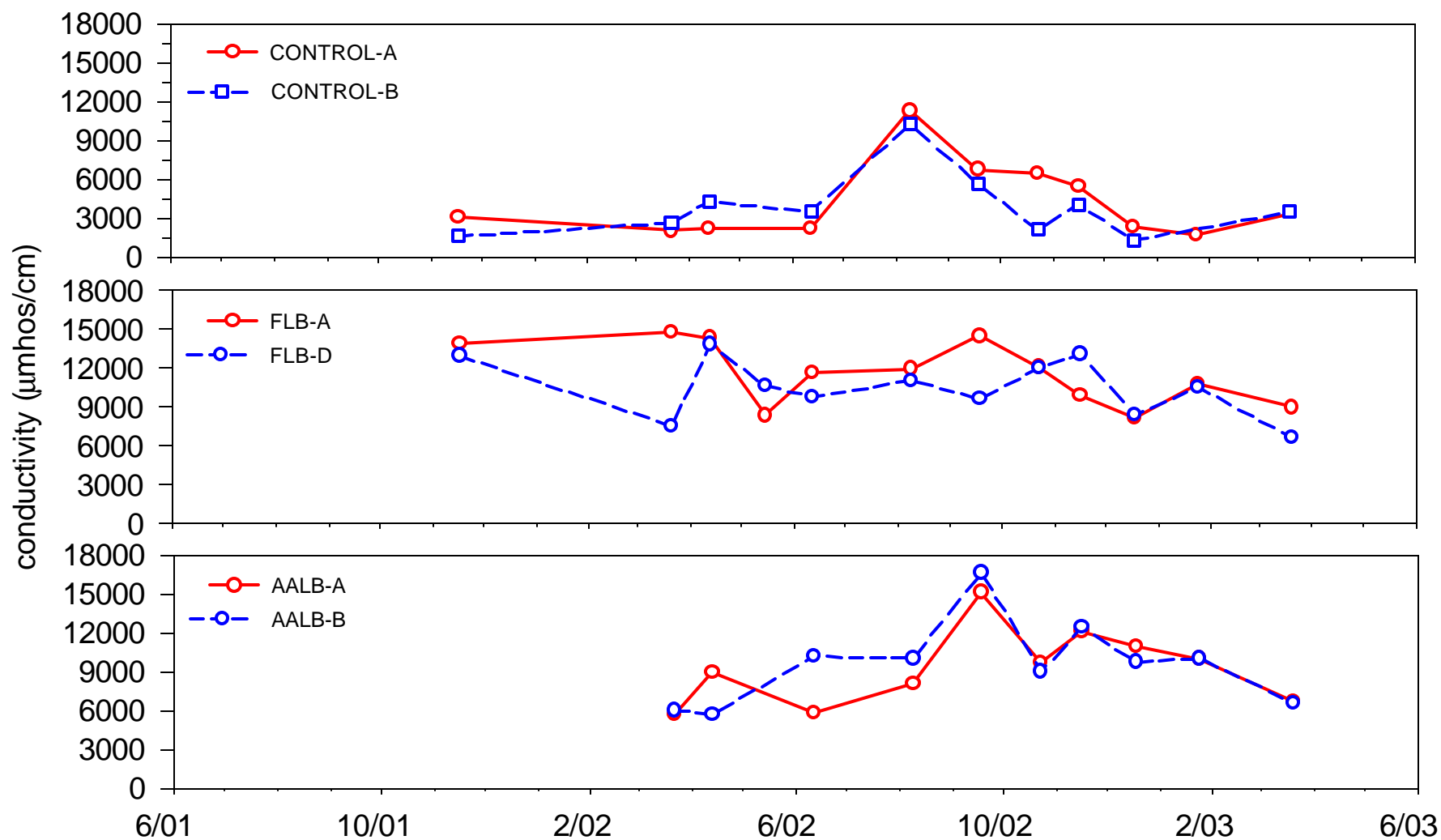


Figure 5-23. Leachate $\text{NH}_3\text{-N}$ vs. Time

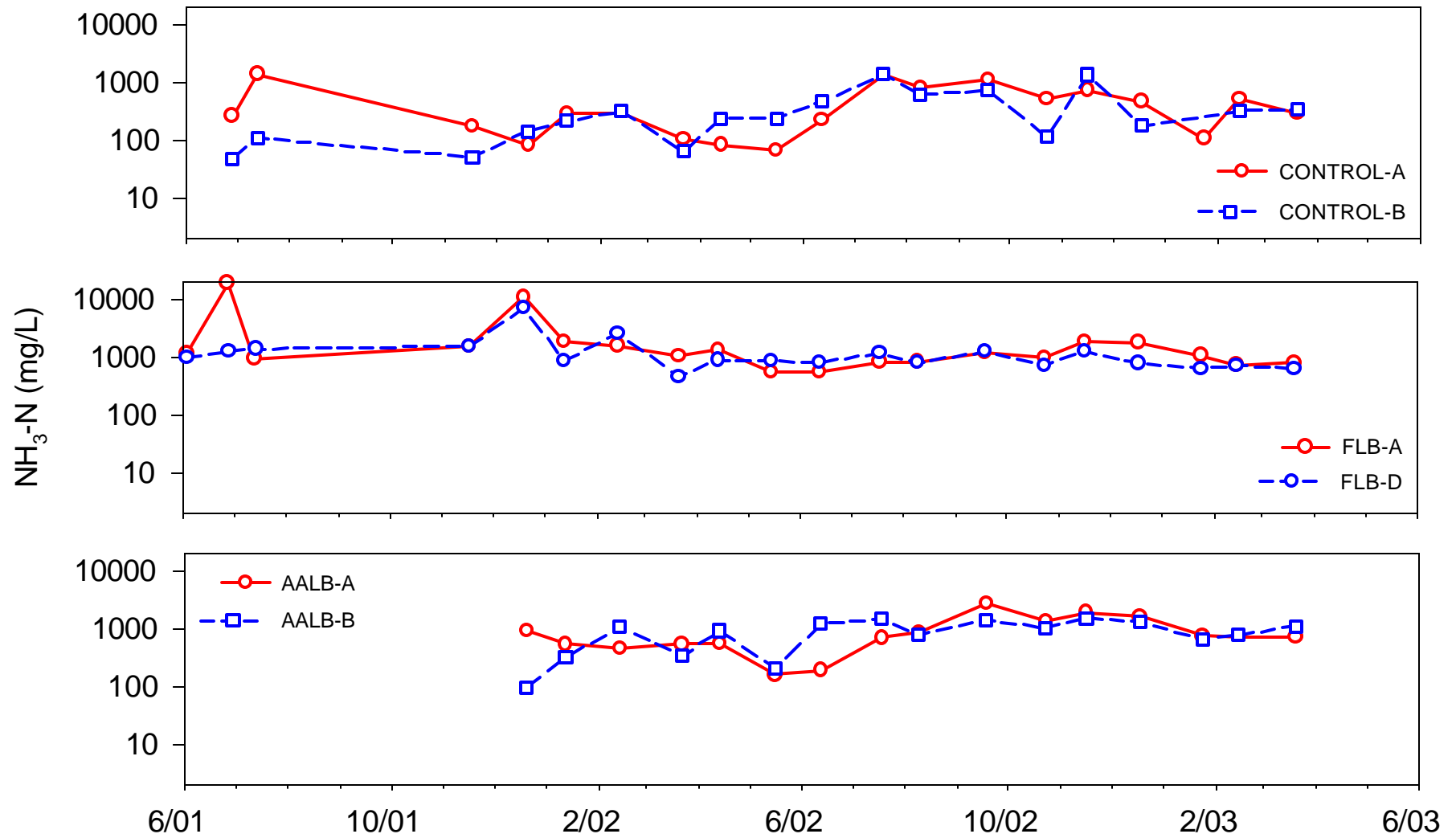


Figure 5-24. Leachate NO₃-N vs. Time

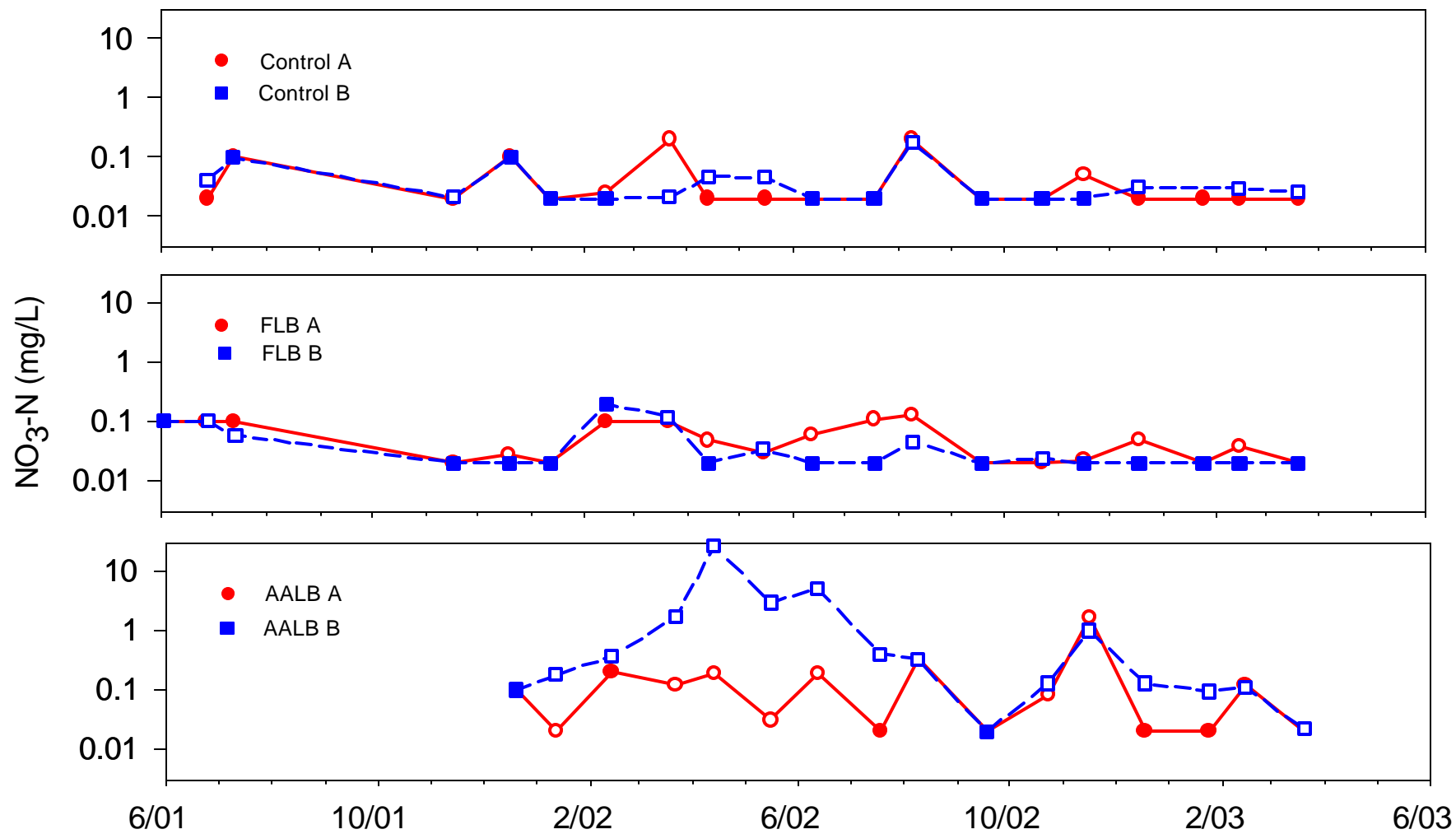
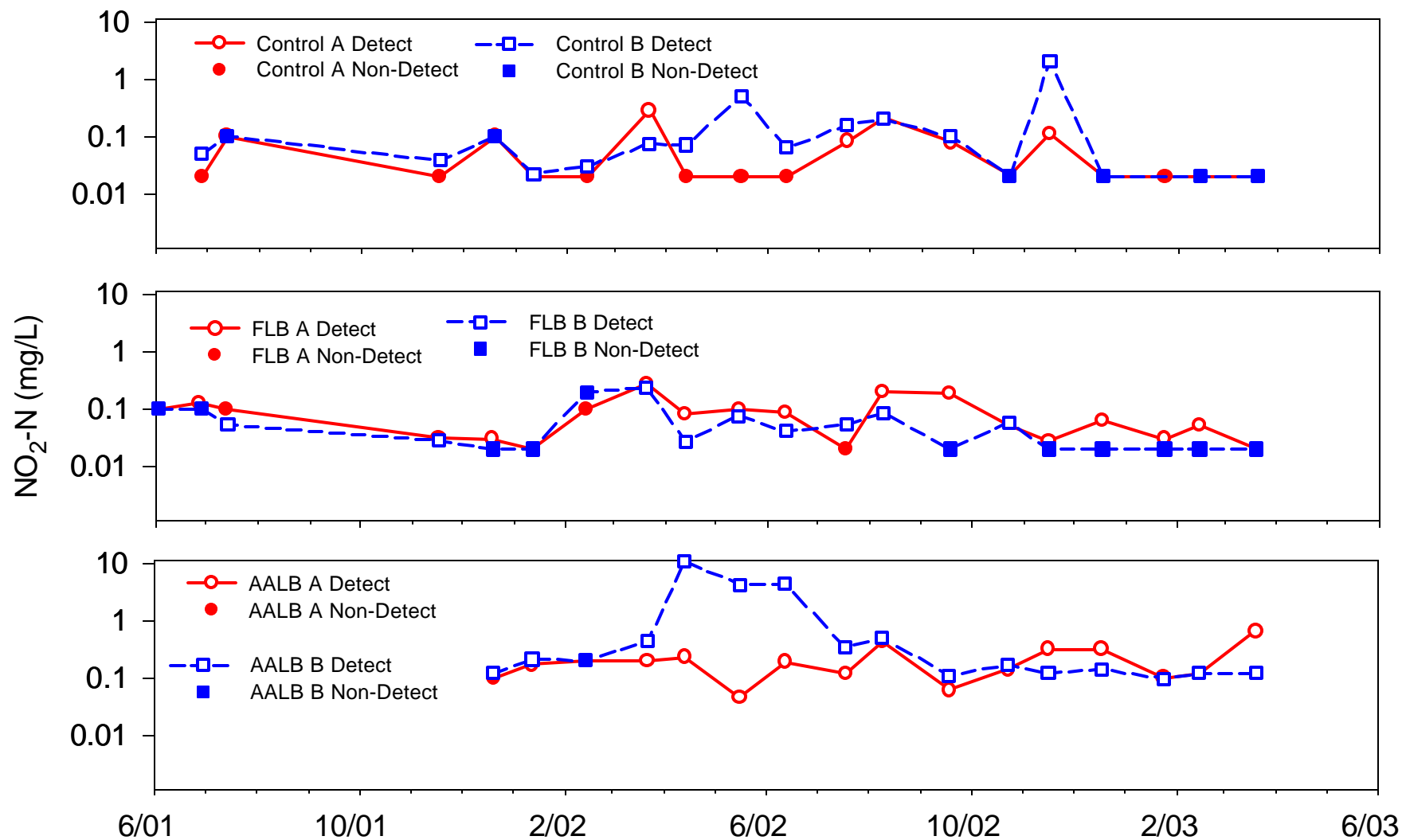


Figure 5-25. Leachate NO₂-N vs. Time



Summary of Leachate o-Phosphate

Leachate o-phosphate measurements were taken on a monthly basis and are displayed graphically in Figure 5-26. Basic statistical parameters calculated from the data are also provided below in Table 5-9. Measurements for total o-Phosphate commenced for the FLB and Control units in June 2001, with AALB measurements beginning in December 2001.

Measurements for the Control and FLB remain relatively stable with results averaging 1 to 3 mg/l. An increase in level to 7 mg/l for FLB 5.2B was recorded in February 2002. A similar increase in the Control unit was recorded in August 2002. o-Phosphate levels in the AALB unit indicate levels ranging between 1 mg/l to 15 mg/l.

TABLE 5-9. SUMMARY OF LEACHATE o-PHOSPHATE

<i>Cell</i>	<i>Minimum [o-Phosphate]</i>	<i>Maximum [o-Phosphate]</i>	<i>Mean [o- Phosphate]</i>	<i>Standard Deviation</i>
FLB 5.1A	1.6	4.6	2.9	0.8
FLB 5.2B	0.5	6.8	2.0	1.3
Control 7.3A	0.1	3.4	1.1	0.8
Control 7.3B	0.3	4.8	1.1	1.0
AALB 7.4A	0.8	15.4	3.4	3.5
AALB 7.4B	1.2	8.2	3.7	2.0

Summary of Leachate Total Phosphorus

Total phosphorous in leachate was measured for the three study units beginning in June 2001 for the Control and FLB, and in December 2001 for the AALB. Total phosphorous measurements are shown graphically in Figure 5-27. Basic statistical parameters calculated from the data are also provided below in Table 5-10.

Total phosphorous results show stable readings for both the Control and FLB units. Readings averaged approximately 2 to 3 mg/l for both of these units. The AALB results fluctuated more in comparison with the Control and FLB units, with measurements from near 0 mg/l to 10 mg/l, with the highest results recorded from July 2002 to August 2002.

TABLE 5-10. SUMMARY OF LEACHATE TOTAL PHOSPHOROUS

<i>Cell</i>	<i>Minimum [Total P]</i>	<i>Maximum [Total P]</i>	<i>Mean [Total P]</i>	<i>Standard Deviation</i>
FLB 5.1A	0.77	5.3	2.9	1.2
FLB 5.2B	1.00	14.2	3.3	2.9
Control 7.3A	0.11	5.3	1.5	1.3
Control 7.3B	0.11	5.6	1.8	1.5
AALB 7.4A	0.92	21.6	5.4	5.1
AALB 7.4B	0.33	10.5	3.8	3.2

Summary of Leachate Total Kjeldahl Nitrogen (TKN)

Total TKN in leachate is taken on a quarterly basis for each of the study units. A summary of the total TKN in leachate vs. time are shown in Figure 5-28. Measurements for Total TKN in the Control and FLB study units began in June 2001. From the Figure, total TKN in the Control unit maintains relatively stable measurements with time, averaging approximately 200 mg/l in unit A and 100 mg/l in unit B. Measurements for total TKN in the FLB study cells show a greater degree of variation than displayed in the control unit, with cells 5.1A and 5.2B ranging in concentrations from approximately 75 mg/l to 1100 mg/l. Sampling for the total TKN in the AALB study units began in March 2002, and showed concentrations varying between near 0 mg/l to over 700 mg/l. Basic statistical parameters calculated from the data are also provided below in Table 5-11.

TABLE 5-11. SUMMARY OF LEACHATE TKN

<i>Cell</i>	<i>Minimum [TKN]</i>	<i>Maximum [TKN]</i>	<i>Mean [TKN]</i>	<i>Standard Deviation</i>
FLB 5.1A	189	1160	812.7	348.8
FLB 5.2B	89.2	1040	585.2	365.6
Control 7.3A	91.9	371	194.1	94.1
Control 7.3B	12.6	390	94.7	123.1
AALB 7.4A	26.5	434	246.7	174.9
AALB 7.4B	100	721	298.6	251.0

Summary of Leachate Total Dissolved Solids

Results are shown graphically in Figure 5-29. Sampling for the Control and FLB units began in June 2002 and sampling for total dissolved solids for the AALB began in March 2002.

Results for the Control unit show consistent readings for total dissolved solids averaging 2,500 mg/l through the sampling event in April 2003. Results for the FLB indicate stable readings averaging 5,500 mg/l. An increase to 25,000 mg/l indicated for the January 2003 sample for FLB 5.1, results returned to 5,500 mg/l for the February 2003. Sample results for the AALB unit range between 5,000 mg/l to 10,000 mg/l.

Figure 5-26. Leachate o-Phosphate vs. Time

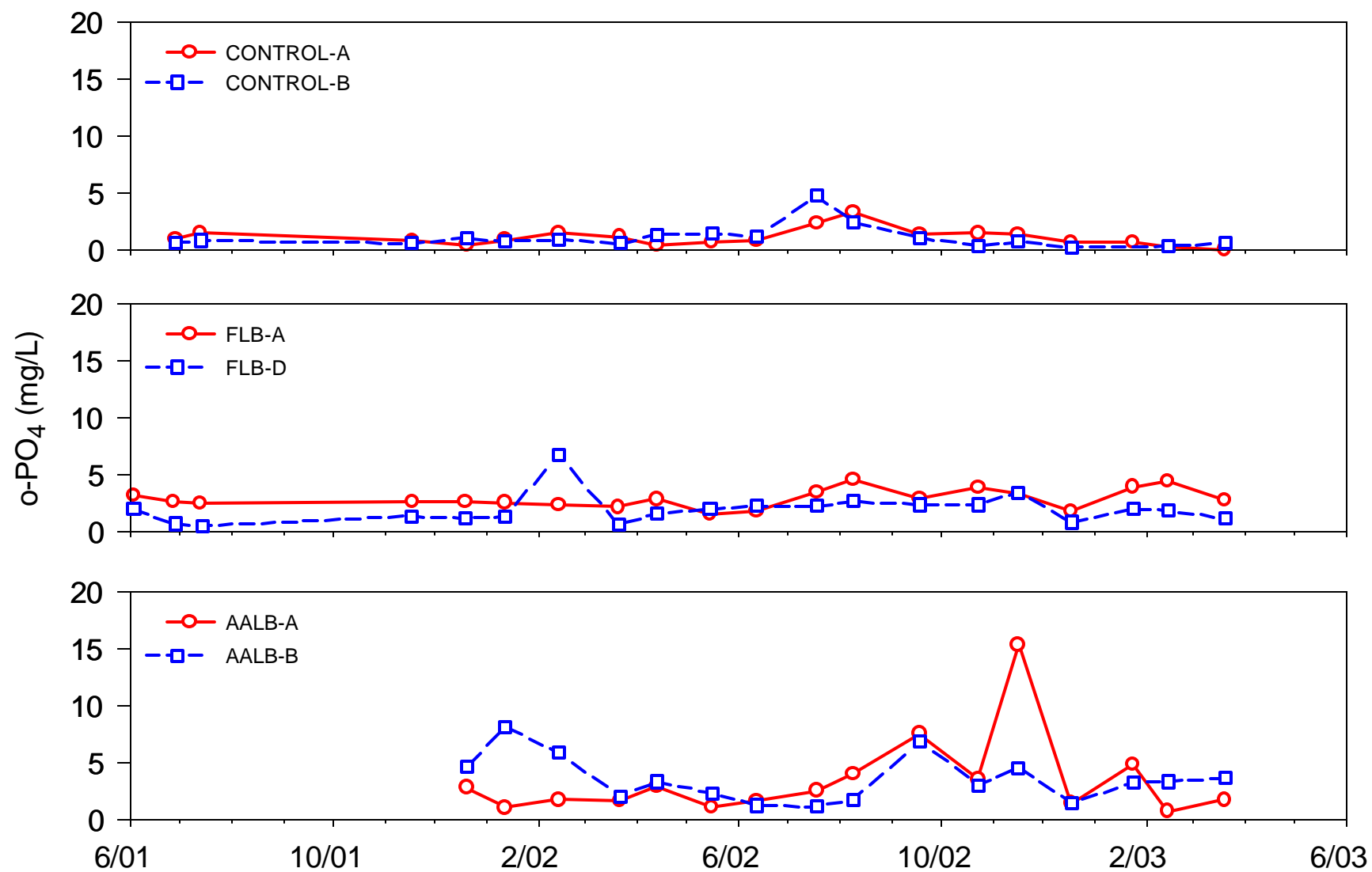


Figure 5-27. Leachate Total Phosphorus vs. Time

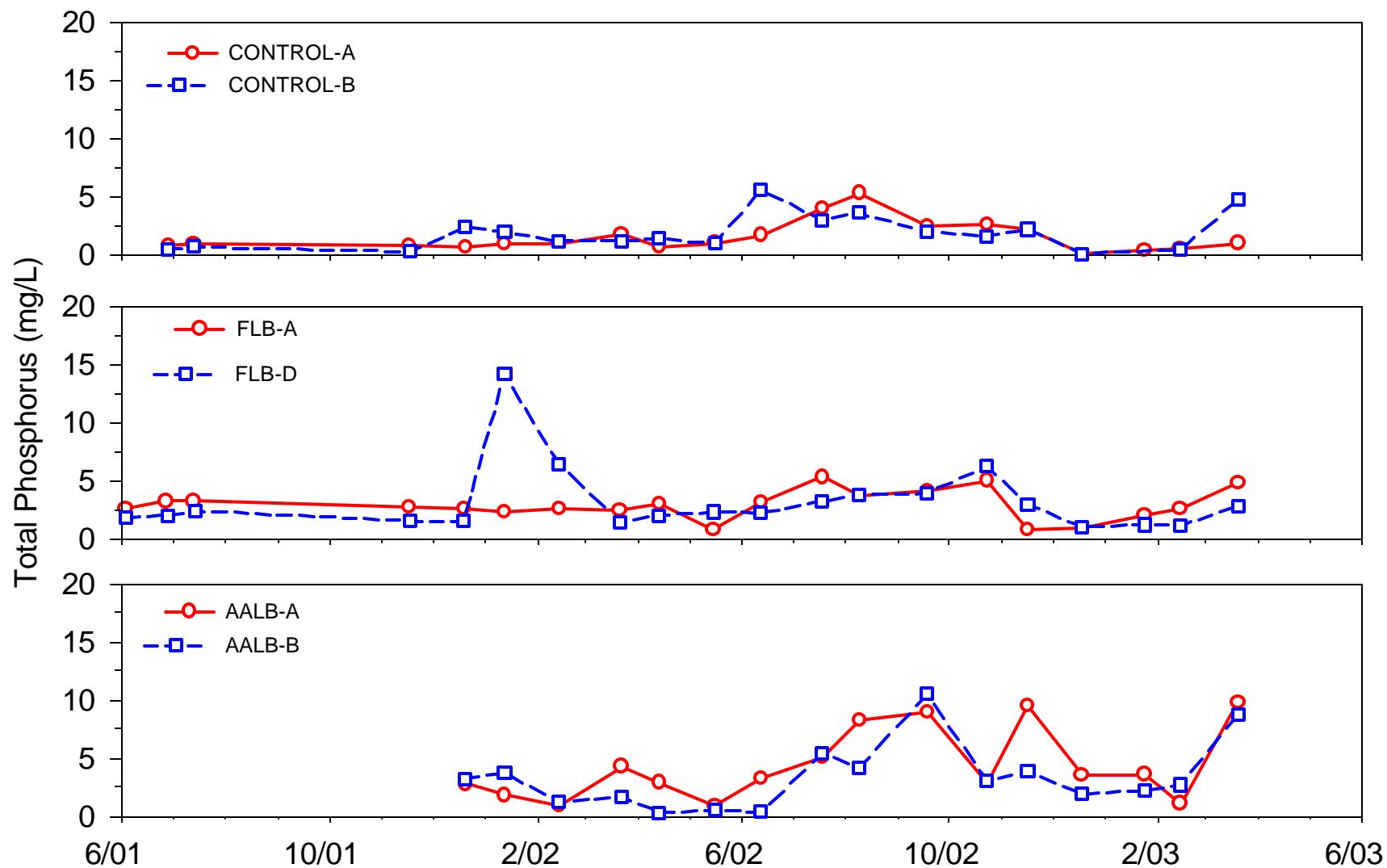


Figure 5-28. Leachate TKN vs. Time

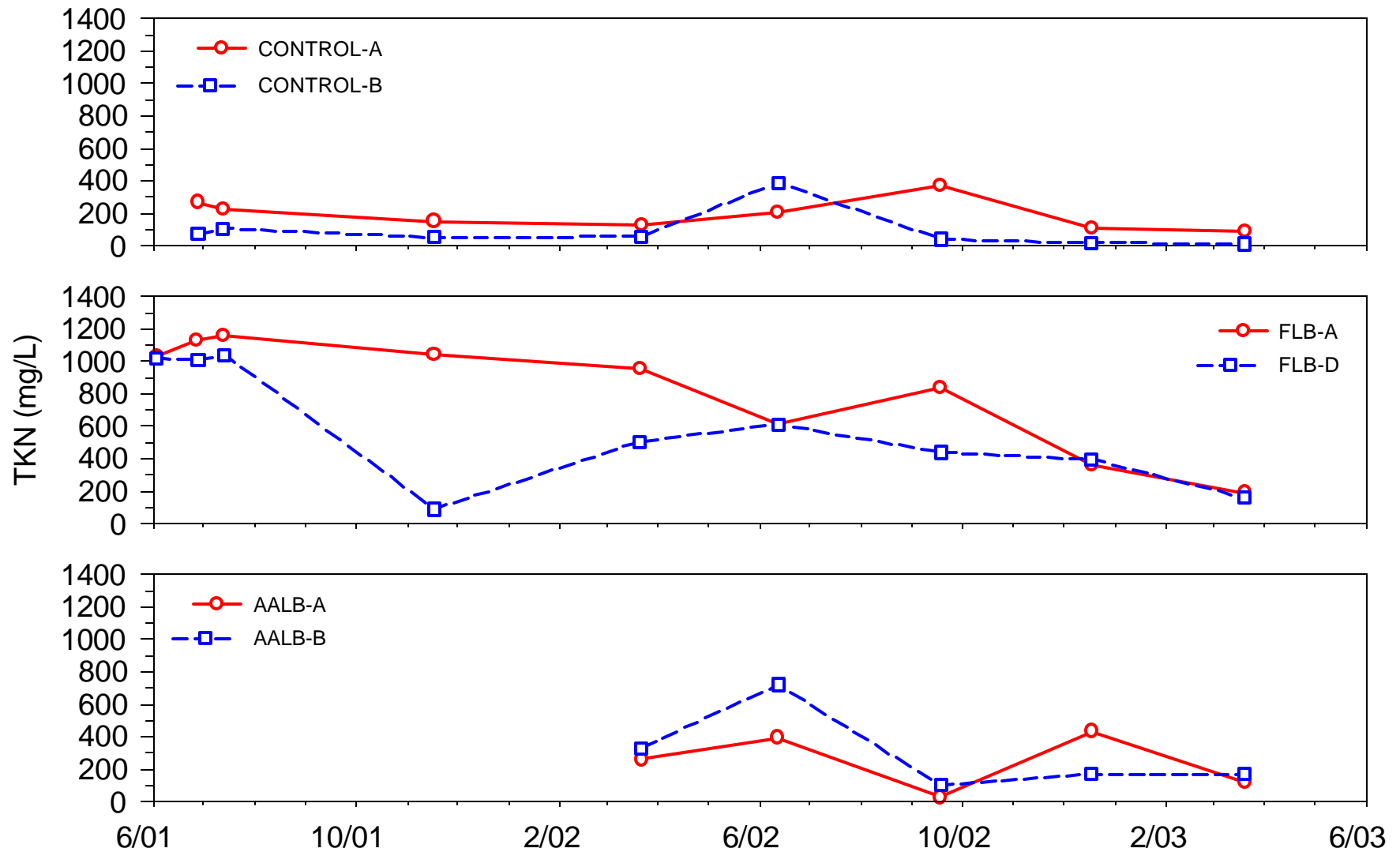
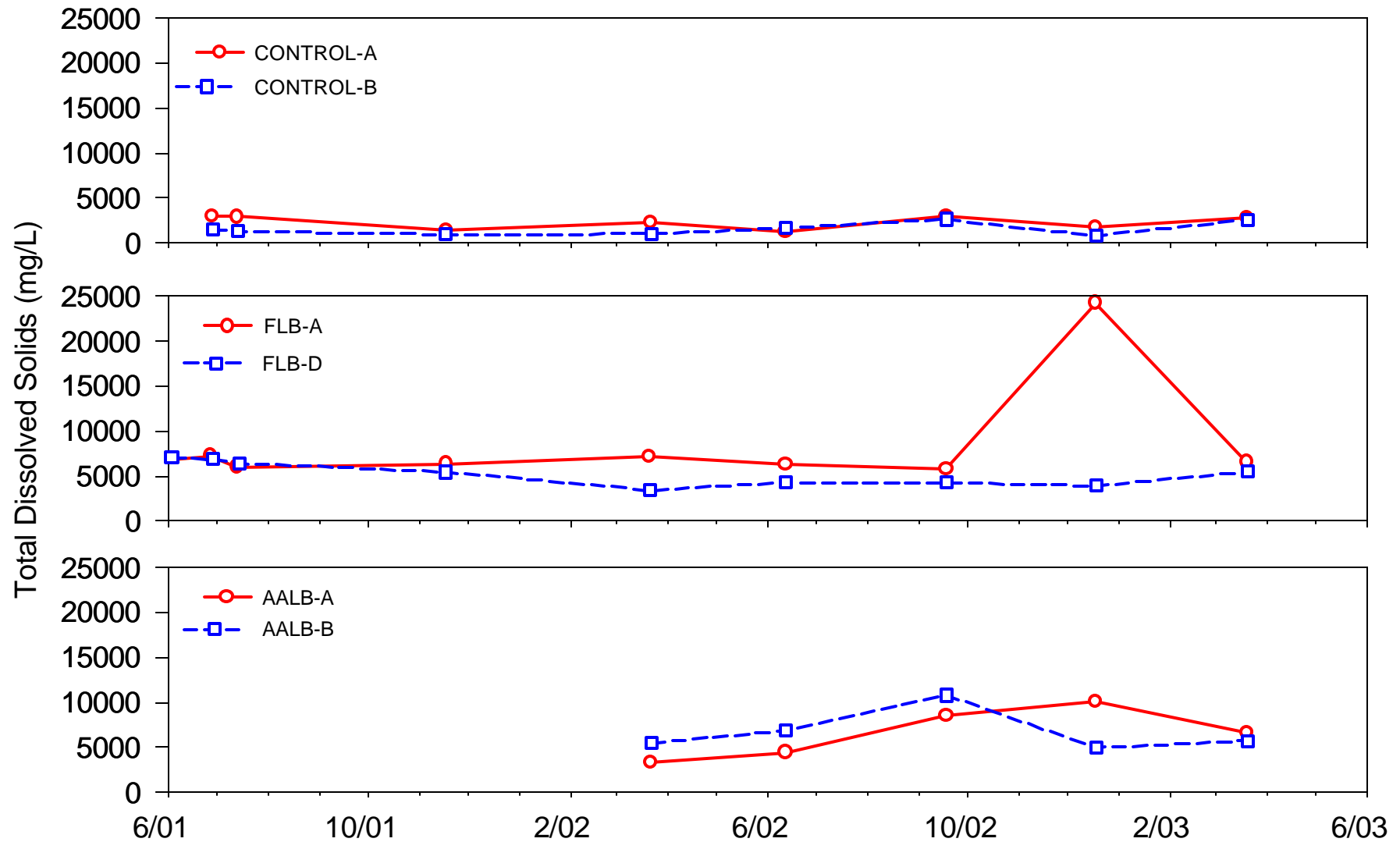


Figure 5-29. Leachate Total Dissolved Solids vs. Time



Summary of Leachate Sulfate

Sulfate was measured in leachate beginning in June 2001 for both the Control and FLB, and beginning in March 2002 for the AALB. The results for concentrations of sulfate in leachate are shown graphically in Figure 5-30.

Sulfate was detected in all three of the study units, but at low concentrations. Sulfate levels in the Control indicate consistent measurements with readings averaging <100 mg/l. Sulfate levels for the control steadily increase with measurements averaging approximately 200 mg/l by March 2003. A sharp spike of 900 mg/l was noted for the March 2003 sampling event.

Sulfate in the FLB remains consistent with readings averaging <100 mg/l. An increase to approximately 200 mg/l was recorded in March 2002, but returned to previous levels the following sampling event. Sulfate measurements in leachate for the AALB indicated similar values to measurements recorded for the FLB, with results averaging <100 mg/l.

Summary of Leachate Chloride

Chloride was measured in leachate beginning in June 2001 for both the Control and FLB units, and beginning in March 2002 for the AALB. Results of the Chloride in leachate are displayed graphically in Figure 5-31.

Chloride was detected in the leachate samples for the Control units within a range of close to 0 mg/l up to approximately 750 mg/l, with results remaining consistent. Samples for the FLB show chloride typically ranging in concentration from approximately 1000mg/l to 2,300 mg/l, with one atypical value at close to 0 mg/l. Chloride levels in the FLB unit were consistently higher than those of the Control. Samples for the AALB show good consistency between the AALB 7.4A and AALB 7.4B units, with concentrations ranging between approximately 500 mg/l to 1,250 mg/l. Results are summarized below in Table 5-12.

TABLE 5-12. SUMMARY OF LEACHATE CHLORIDE

<i>Cell</i>	<i>Minimum [Chloride]</i>	<i>Maximum [Chloride]</i>	<i>Mean [Chloride]</i>	<i>Standard Deviation</i>
FLB 5.1A	1.0	2350	163.0	552.31
FLB 5.2B	1.0	2340	150.1	548.46
Control 7.3A	1.0	389	24.1	91.14
Control 7.3B	1.0	1010	109.3	263.81
AALB 7.4A	1.0	1650	484.2	554.73
AALB 7.4B	2.9	2580	582.1	845.87

Summary of Leachate Total Potassium

Total potassium in leachate was measured for the three study units beginning in June 2001 for the Control and FLB units, and in March 2002 for the AALB unit. Figure 5-32 shows results for the three study units.

Total potassium measurements for the Control sample indicate relatively consistent results with readings averaging 100 mg/l. The FLB unit indicates more varied results with results ranging from 400 mg/l to nearly 1,000 mg/l. The AALB unit indicates more consistent readings with results averaging 500 mg/l.

Summary of Leachate Volatile Organic Acids

Samples of volatile organic acids (VOAs) in leachate are collected on a monthly basis. Samples are collected for acetic, butyric, formic, and lactic acids. Sample results are shown graphically for each representative acid and can be found in Figures 5-33 through 5-38. Samples were collected for the three study units beginning November 2001 for the Control and FLB, and in December 2001 for the AALB.

Acetic Acid --

Acetic acid in leachate was typically detected in the Control and FLB at levels near 0 mg/l. The Control unit showed the odd spike early in the sampling program up to approximately 1,000 mg/l. The FLB showed spikes of up to approximately 2,500 mg/l. Acetic acid levels in both the Control and FLB returned to near 0 mg/l following the elevated readings.

Acetic acid in leachate in the AALB unit shows much more varied readings over the same period from near 0 mg/l up to near 2,500 mg/l. These varied results continue throughout the period to date. Basic statistical parameters calculated from the data are also provided below.

Butyric Acid --

Butyric acid in leachate was detected in the Control and FLB units at levels near 0 mg/l. The Control and FLB results indicate relatively stable measurements with occasional peaks that range between 0 mg/l and 2,000 mg/l. In the cases of the elevated readings, levels returned to near 0 mg/l in the subsequent sampling events.

Levels of butyric acid in the AALB showed varied results in comparison to the Control and FLB units. Measurements indicate ranges between 0 mg/l and to 1,000 mg/l.

Figure 5-30. Leachate Sulfate vs. Time

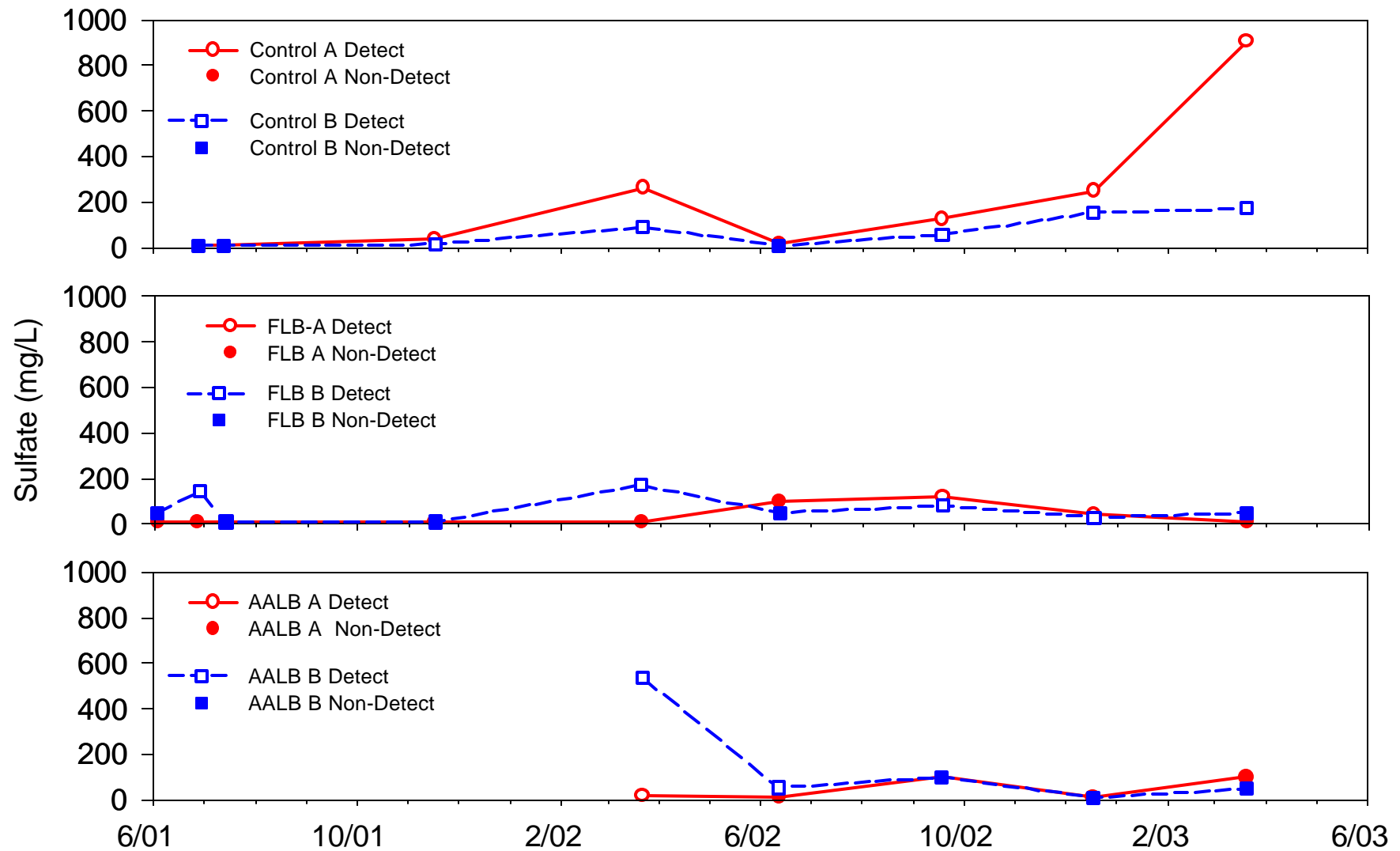


Figure 5-31. Leachate Chloride vs. Time

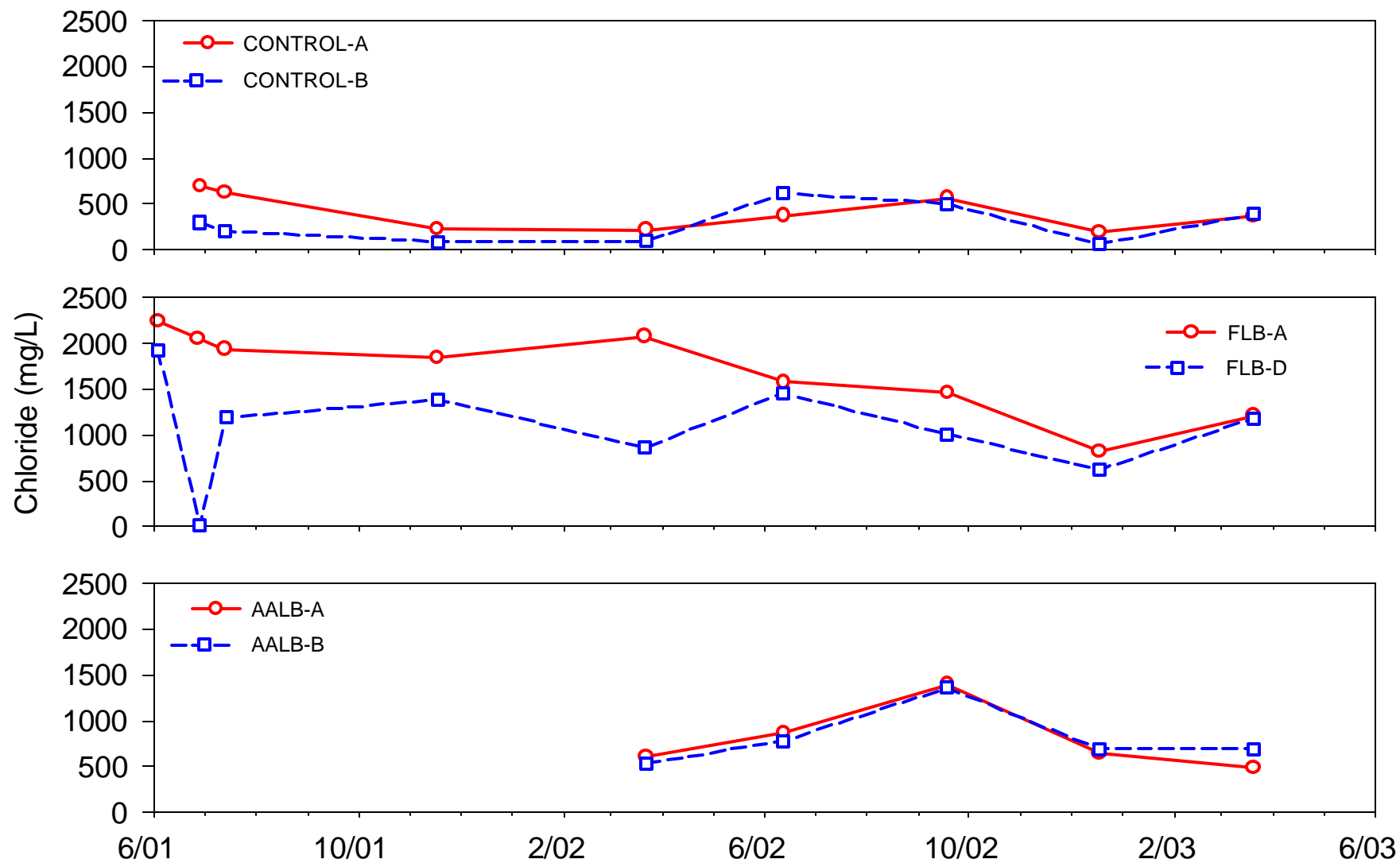
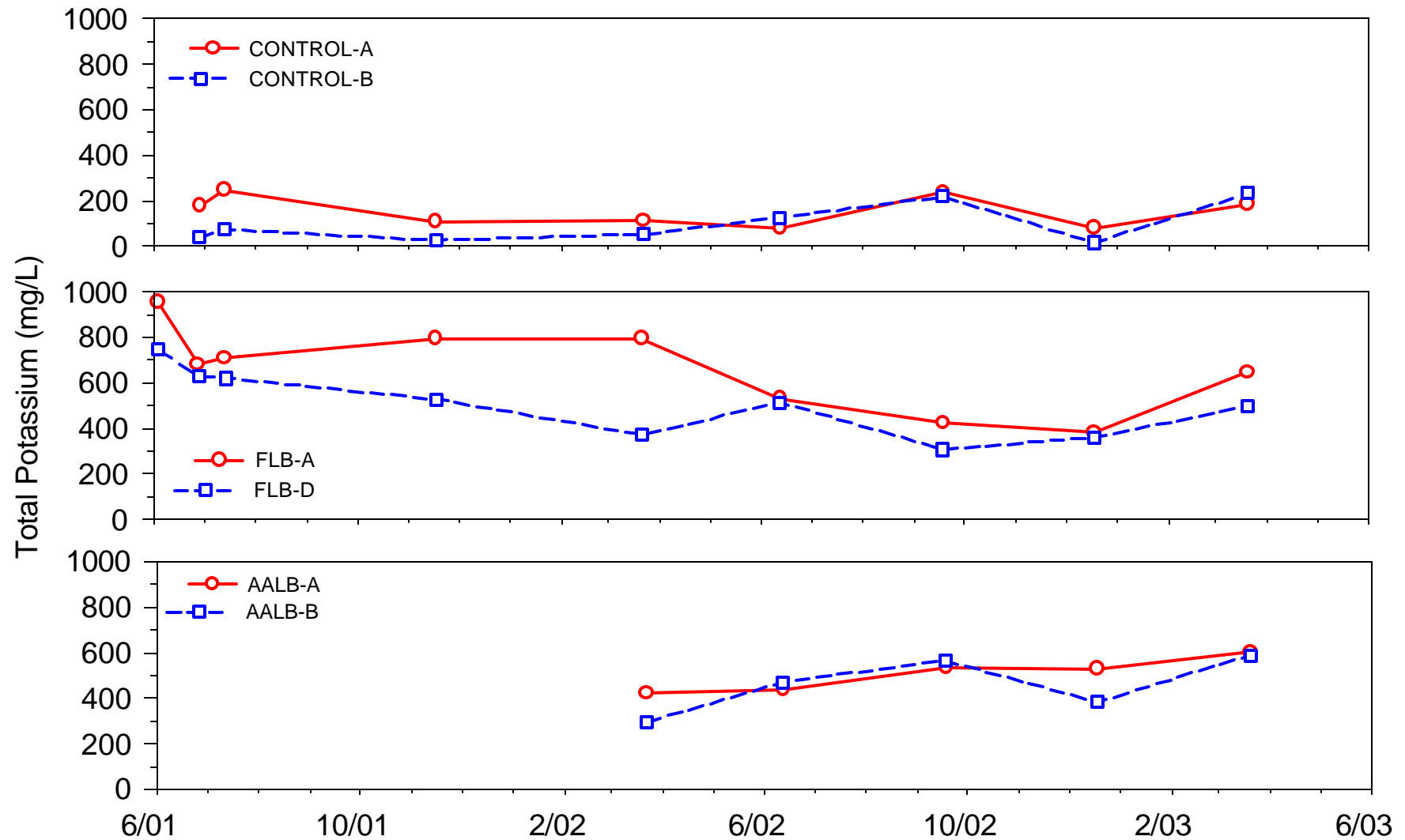


Figure 5-32. Leachate Total Potassium vs. Time



Formic Acid --

Formic acid in leachate was detected in the three study units, with sampling beginning in December 2001. Figure 5-35 shows the graphical results of formic acid levels in leachate for the three study units.

Levels of formic acid for all three of the study units showed varying results ranging from near 0 mg/l to nearly 25 mg/l. Results for the Control and FLB units showed stabilization near 0 mg/l beginning in the August 2002 sampling event, while the AALB began stabilizing to near 0 mg/l in the February 2003 sampling period.

Lactic Acid --

Results for lactic acid in leachate samples are shown graphically in Figure 5-36. Sampling for lactic acid began in November 2002 for the Control and FLB units, and in December 2002 for the AALB unit. Results indicate non-detects for a majority of the sampling events.

Propionic Acid --

Propionic acid samples were collected in the three study units beginning in November 2001 for the Control and FLB units, and in December 2001 for the AALB. Sample results are shown graphically in Figure 5-37.

Levels of propionic acid in the Control and FLB units were relatively stable with results averaging 0 mg/l. The FLB unit showed two spikes in the results with values near 3,000 mg/l in April and November 2002, levels returned to near 0 mg/l in the following sampling event. The AALB unit showed more varied results with reading ranging from 0 mg/l to 2000 mg/l.

Pyruvic Acid --

Pyruvic acid samples were collected for all three units of study beginning in December 2002. Results are shown graphically in Figure 5-38.

Pyruvic acid levels show varied results in the all three of the study units. Results for the three units' range in concentration from near 0mg/l to 175 mg/l in the FLB. Similar results were found for the Control and AALB.

Figure 5-33. Leachate Acetic Acid vs. Time

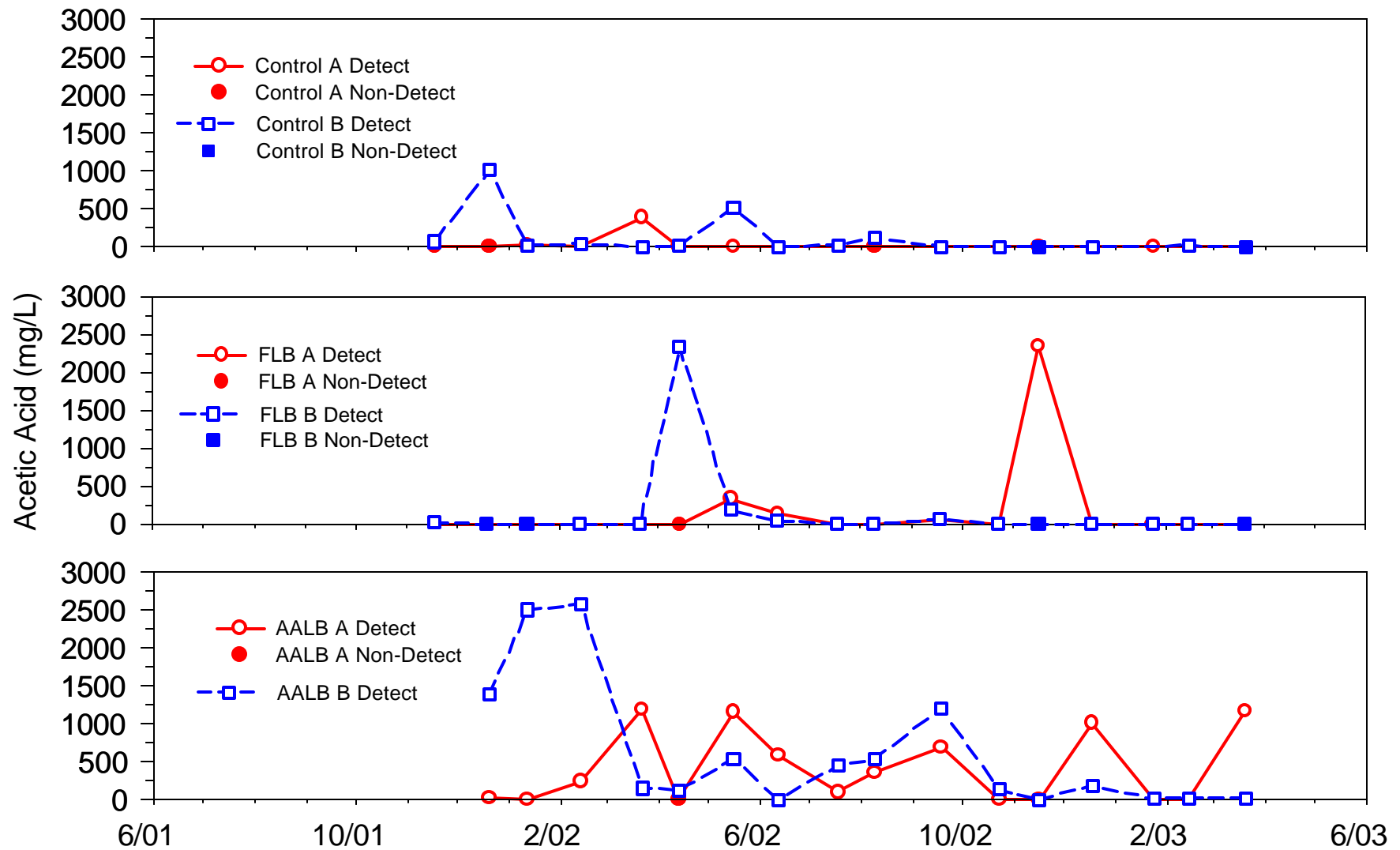


Figure 5-34. Leachate Butyric Acid vs. Time

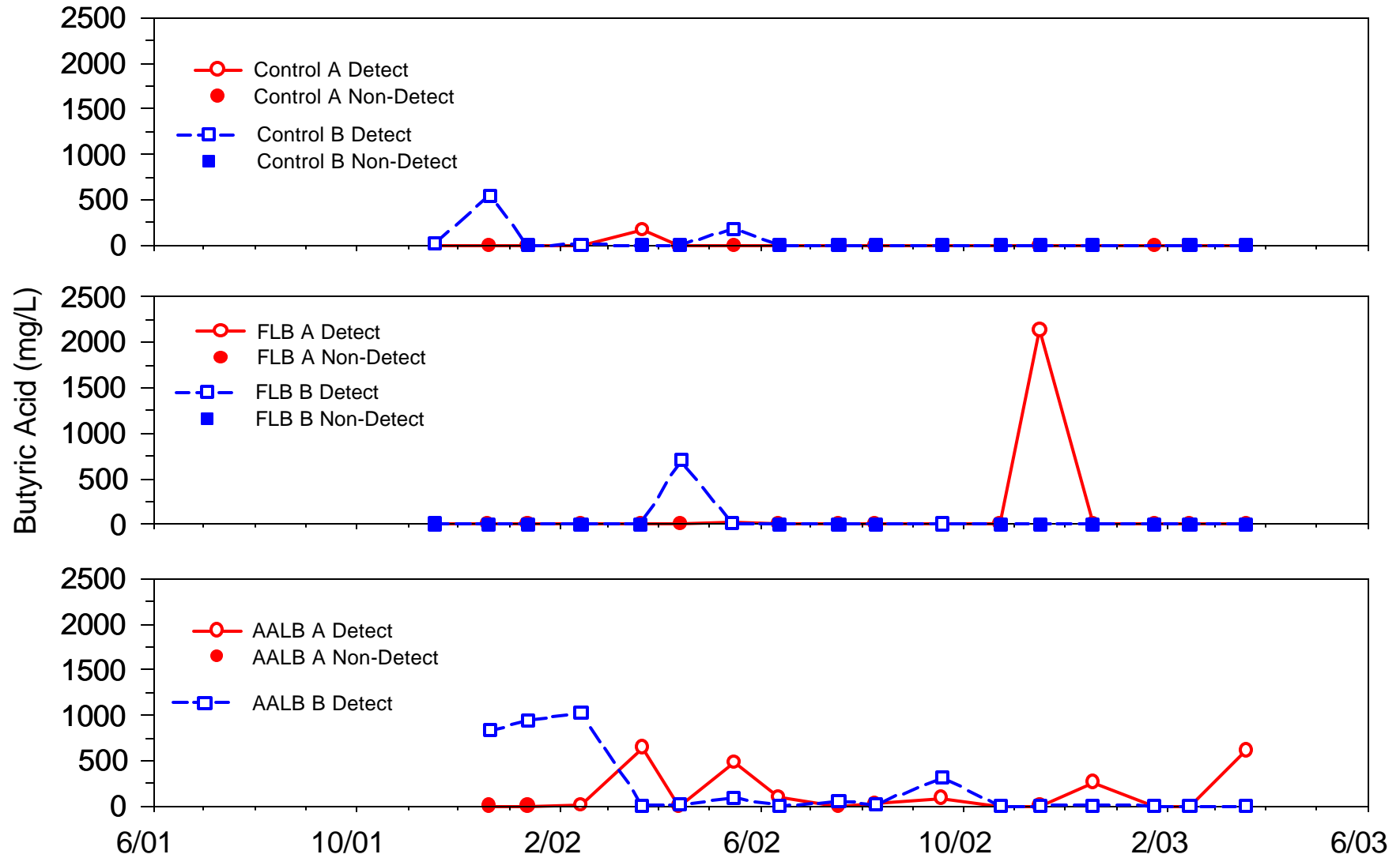


Figure 5-35. Leachate Formic Acid vs. Time

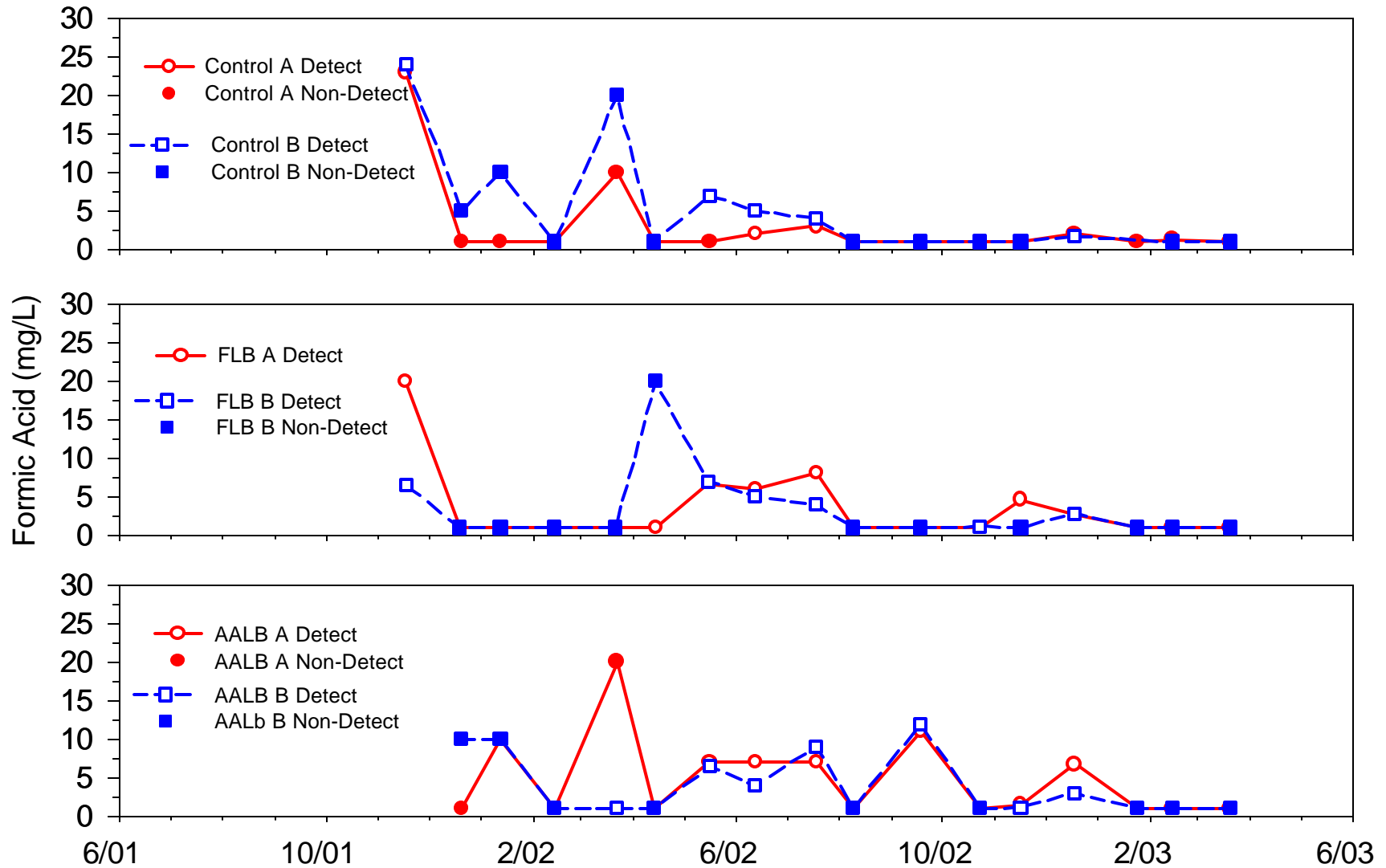


Figure 5-36. Leachate Lactic Acid vs. Time

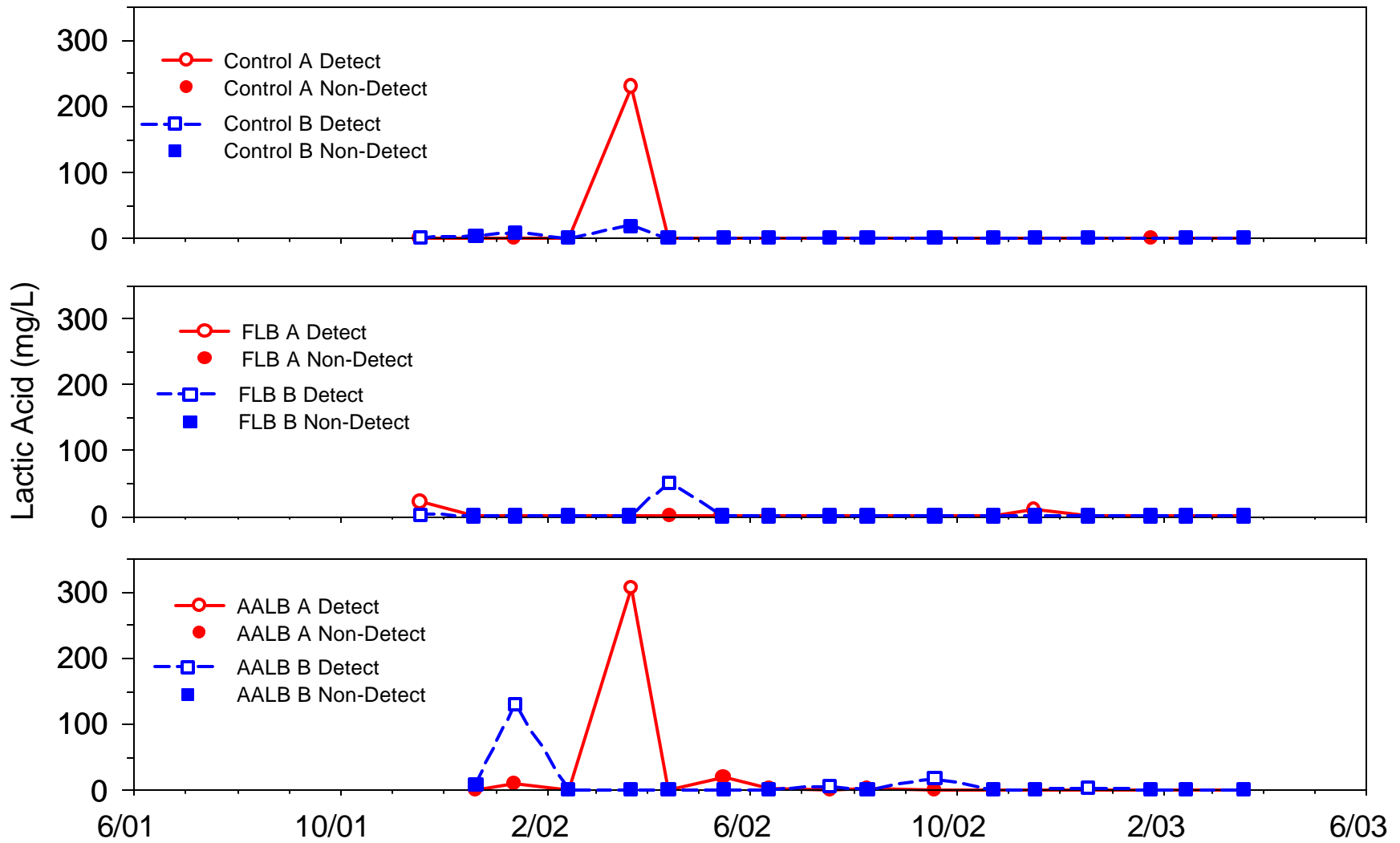


Figure 5-37. Leachate Propionic Acid vs. Time

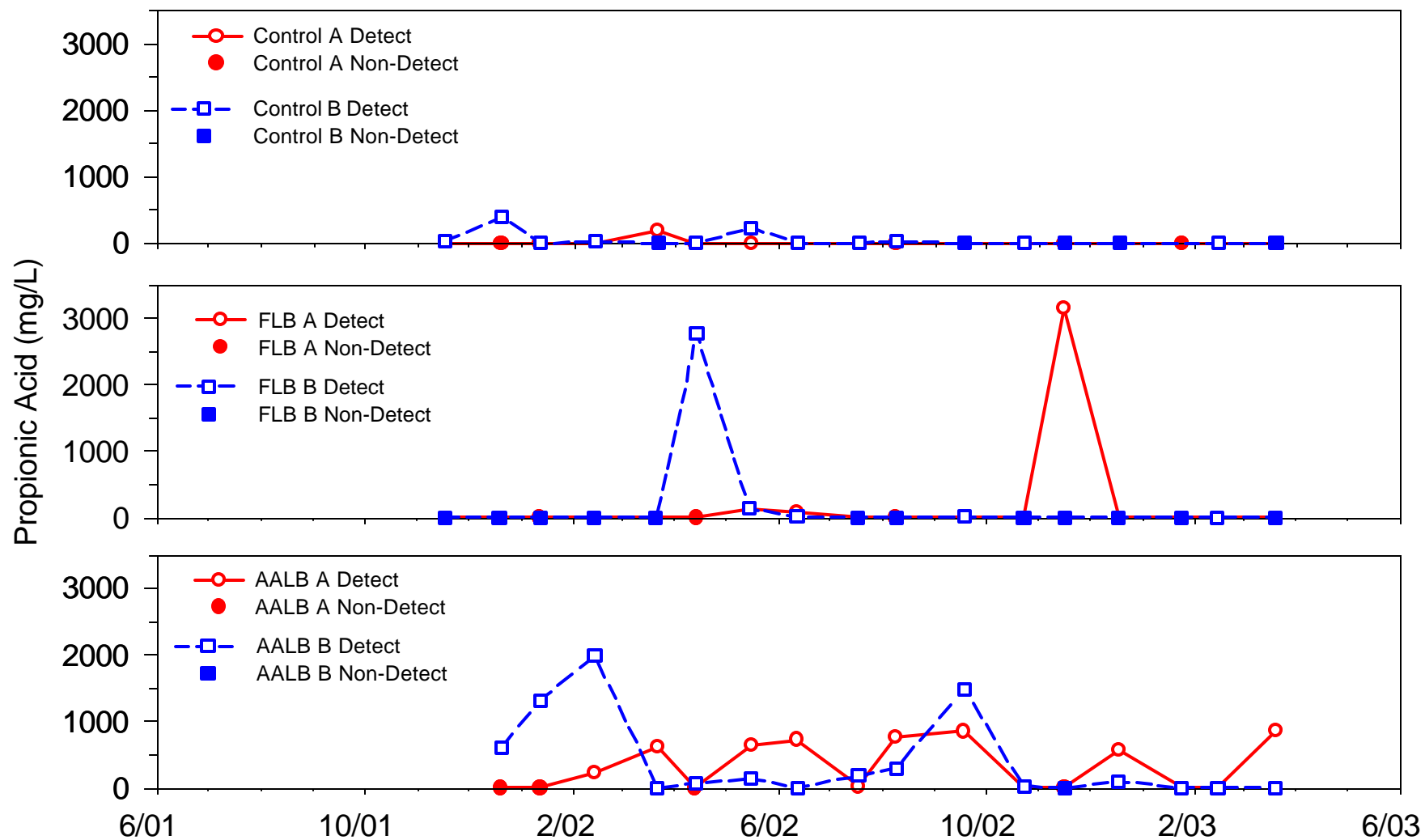
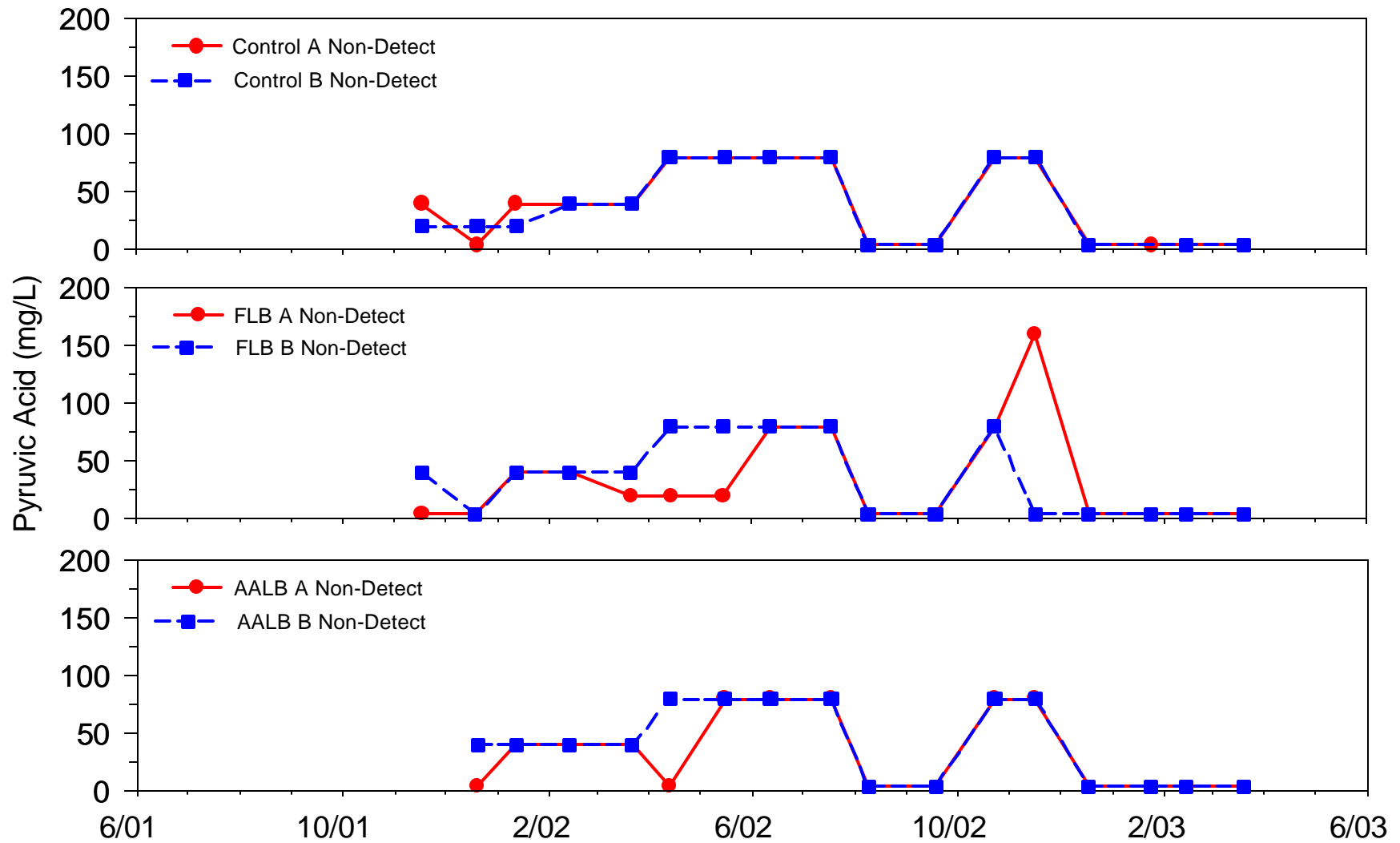


Figure 5-38. Leachate Pyruvic Acid vs. Time



Summary of Leachate Volatile Organic Compounds (VOCs)

Volatile Organic Compounds (VOCs) in leachate are summarized in a series of detection frequency tables shown in Tables 5-13 through 5-18. The tables include a list of the VOC constituents that were analyzed as well as the number of samples taken for each study cell, the number of non-detects, number of readings between 1.0 and 100 µg/l, and number of readings greater than 100 µg/l for each compound analyzed. Samples were analyzed using EPA Method 8260.

VOC constituents that were present in the Control, FLB and AALB units include benzene, toluene, ethylbenzene, total xylenes, 1,4-dichlorobenzene and methylene chloride. These VOC constituents were detected in all of the study units. A total of 9 percent of the samples were within the 1.0-100 ug/l range, with 4 percent of the samples are levels greater than 100 ug/l.

TABLE 5-13. VOLATILE ORGANIC COMPOUNDS (VOCS) IN LEACHATE CONTROL 7.3A, JUNE 26, 2001 THROUGH DECEMBER 16, 2002

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,1,1,2-Tetrachloroethane	8	8	0	0
1,1,1-Trichloroethane	8	8	0	0
1,1,2,2-Tetrachloroethane	8	8	0	0
1,1,2-Trichloroethane	8	8	0	0
1,1-Dichloroethane	8	7	1	0
1,1-Dichloroethene	8	8	0	0
1,2,3-Trichloropropane	8	8	0	0
1,2-Dibromo-3-Chloropropane	8	8	0	0
1,2-Dibromoethane	8	8	0	0
1,2-Dichlorobenzene	8	8	0	0
1,2-Dichloroethane	8	8	0	0
1,2-Dichloropropane	8	8	0	0
1,4-Dichlorobenzene	8	2	6	0
2-Chloroethylvinyl ether	8	8	0	0
2-Hexanone	8	8	0	0
Acetone	8	5	1	2
Acrolein	8	8	0	0
Acrylonitrile	8	8	0	0
Benzene	8	0	8	0
Bromochloromethane	8	8	0	0
Bromoform	8	8	0	0
Bromomethane	8	8	0	0
Carbon Disulfide	8	7	1	0
Carbon Tetrachloride	8	8	0	0
Chlorobenzene	8	8	0	0
Chloroethane	8	8	0	0
Chloroform	8	7	1	0
Chloromethane	8	8	0	0
cis-1,2-Dichloroethene	8	8	0	0
cis-1,3-Dichloropropene	8	8	0	0
Dibromochloromethane	8	8	0	0

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Dibromomethane	8	8	0	0
Dichlorobromomethane	8	8	0	0
Dichlorodifluoromethane	8	8	0	0
Ethyl methacrylate	8	8	0	0
Ethylbenzene	8	0	8	0
Iodomethane	8	8	0	0
Methyl Ethyl Ketone	8	5	1	2
Methyl Isobutyl Ketone	8	6	0	2
Methylene chloride	8	2	6	0
Styrene	8	8	0	0
Tetrachloroethene	8	6	2	0
Toluene	8	3	3	2
Total Xylene	8	0	4	4
trans-1,2-Dichloroethene	8	8	0	0
trans-1,3-Dichloropropene	8	8	0	0
trans-1,4-Dichloro-2-butene	8	8	0	0
Trichloroethene	8	6	2	0
Trichlorofluoromethane	8	8	0	0
Vinyl acetate	8	8	0	0
Vinyl chloride	8	6	2	2
Total	408	348	46	14

Samples were analyzed using EPA Method 8260B (B)

TABLE 5-14. VOLATILE ORGANIC COMPOUNDS (VOCs) IN LEACHATE CONTROL 7.3B, JUNE 26, 2001 THROUGH DECEMBER 16, 2002

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,1,1,2-Tetrachloroethane	7	7	0	0
1,1,1-Trichloroethane	7	7	0	0
1,1,2,2-Tetrachloroethane	7	7	0	0
1,1,2-Trichloroethane	7	7	0	0
1,1-Dichloroethane	7	7	0	0
1,1-Dichloroethene	7	7	0	0
1,2,3-Trichloropropane	7	7	0	0
1,2-Dibromo-3-Chloropropane	7	7	0	0
1,2-Dibromoethane	7	7	0	0
1,2-Dichlorobenzene	7	7	0	0
1,2-Dichlorobethane	7	7	0	0
1,2-Dichloropropane	7	7	0	0
1,4-Dichlorobenzene	7	1	6	0
2-Chloroethylvinyl ether	7	7	0	0
2-Hexanone	7	7	0	0
Acetone	7	3	1	3
Acrolein	7	7	0	0
Acrylonitrile	7	7	0	0
Benzene	7	2	5	0
Bromochloromethane	7	7	0	0

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Bromoform	7	7	0	0
Bromomethane	7	7	0	0
Carbon Disulfide	7	7	0	0
Carbon Tetrachloride	7	7	0	0
Chlorobenzene	7	7	0	0
Chloroethane	7	7	0	0
Chloroform	7	6	1	0
Chloromethane	7	7	0	0
cis-1,2-Dichloroethene	7	7	0	0
cis-1,3-Dichloropropene	7	7	0	0
Dibromochloromethane	7	7	0	0
Dibromomethane	7	7	0	0
Dichlorobromomethane	7	7	0	0
Dichlorodifluoromethane	7	7	0	0
Ethyl methacrylate	7	7	0	0
Ethylbenzene	7	0	4	2
Iodomethane	7	7	0	0
Methyl Ethyl Ketone	7	4	0	2
Methyl Isobutyl Ketone	7	6	1	0
Methylene chloride	7	5	2	0
Styrene	7	7	0	0
Tetrachloroethene	7	7	0	0
Toluene	7	2	4	1
Total Xylene	7	0	2	5
trans-1,2-Dichloroethene	7	7	0	0
trans-1,3-Dichloropropene	7	7	0	0
trans-1,4-Dichloro-2-butene	7	7	0	0
Trichloroethene	7	7	0	0
Trichlorofluoromethane	7	7	0	0
Vinyl acetate	7	7	0	0
Vinyl chloride	7	3	4	0
Total	357	313	30	14

Samples were analyzed using EPA Method 8260B (B)

**TABLE 5-15. VOLATILE ORGANIC COMPOUNDS (VOCs) IN LEACHATE
FLB 5.1A, JUNE 1, 2001 THROUGH DECEMBER 16, 2002**

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,1,1,2-Tetrachloroethane	9	9	0	0
1,1,1-Trichloroethane	9	9	0	0
1,1,2,2-Tetrachloroethane	9	9	0	0
1,1,2-Trichloroethane	9	9	0	0
1,1-Dichloroethane	9	9	0	0
1,1-Dichloroethene	9	9	0	0
1,2,3-Trichloropropane	9	9	0	0
1,2-Dibromo-3-Chloropropane	9	9	0	0
1,2-Dibromoethane	9	9	0	0

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,2-Dichlorobenzene	9	9	0	0
1,2-Dichloroethane	9	9	0	0
1,2-Dichloropropane	9	9	0	0
1,4-Dichlorobenzene	9	1	8	0
2-Chloroethylvinyl ether	9	9	0	0
2-Hexanone	9	8	0	1
Acetone	9	7	1	1
Acrolein	9	0	0	0
Acrylonitrile	9	9	0	0
Benzene	9	8	1	0
Bromochloromethane	9	9	0	0
Bromoform	9	9	0	0
Bromomethane	9	9	0	0
Carbon Disulfide	9	9	0	0
Carbon Tetrachloride	9	9	0	0
Chlorobenzene	9	9	0	0
Chloroethane	9	9	0	0
Chloroform	9	9	0	0
Chloromethane	9	9	0	0
Cis-1,2-Dichloroethene	9	9	0	0
Cis-1,3-Dichloropropene	9	9	0	0
Dibromochloromethane	9	9	0	0
Dibromomethane	9	9	0	0
Dichlorobromomethane	9	9	0	0
Dichlorodifluoromethane	9	9	0	0
Ethyl methacrylate	9	9	0	0
Ethylbenzene	9	0	9	0
Iodomethane	9	9	0	0
Methyl Ethyl Ketone	9	4	3	2
Methyl Isobutyl Ketone	9	7	2	0
Methylene chloride	9	4	5	0
Styrene	9	9	0	0
Tetrachloroethene	9	9	0	0
Toluene	9	1	8	0
Total Xylene	9	0	2	7
Trans-1,2-Dichloroethene	9	9	0	0
Trans-1,3-Dichloropropene	9	9	0	0
Trans-1,4-Dichloro-2-butene	9	9	0	0
Trichloroethene	9	9	0	0
Trichlorofluoromethane	9	9	0	0
Vinyl acetate	9	9	0	0
Vinyl chloride	9	8	1	0
Total	459	408	40	11

Samples were analyzed using EPA Method 8260B (B)

**TABLE 5-16. VOLATILE ORGANIC COMPOUNDS (VOCS) IN LEACHATE
FLB 5.2B, JUNE 1, 2001 THROUGH DECEMBER 16, 2002**

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,1,1,2-Tetrachloroethane	8	8	0	0
1,1,1-Trichloroethane	8	8	0	0
1,1,2,2-Tetrachloroethane	8	8	0	0
1,1,2-Trichloroethane	8	8	0	0
1,1-Dichloroethane	8	8	0	0
1,1-Dichloroethene	8	8	0	0
1,2,3-Trichloropropane	8	8	0	0
1,2-Dibromo-3-Chloropropane	8	8	0	0
1,2-Dibromoethane	8	7	1	0
1,2-Dichlorobenzene	8	8	0	0
1,2-Dichloroethane	8	7	1	0
1,2-Dichloropropane	8	8	0	0
1,4-Dichlorobenzene	8	1	7	0
2-Chloroethylvinyl ether	8	8	0	0
2-Hexanone	8	8	0	0
Acetone	8	3	3	2
Acrolein	8	8	0	0
Acrylonitrile	8	8	0	0
Benzene	8	2	6	0
Bromochloromethane	8	8	0	0
Bromoform	8	8	0	0
Bromomethane	8	8	0	0
Carbon Disulfide	8	8	0	0
Carbon Tetrachloride	8	8	0	0
Chlorobenzene	8	7	1	0
Chloroethane	8	8	0	0
Chloroform	8	7	1	0
Chloromethane	8	8	0	0
cis-1,2-Dichloroethene	8	8	0	0
cis-1,3-Dichloropropene	8	8	0	0
Dibromochloromethane	8	8	0	0
Dibromomethane	8	8	0	0
Dichlorobromomethane	8	8	0	0
Dichlorodifluoromethane	8	8	0	0
Ethyl methacrylate	8	8	0	0
Ethylbenzene	8	0	7	1
Iodomethane	8	8	0	0
Methyl Ethyl Ketone	8	5	2	1
Methyl Isobutyl Ketone	8	7	1	0
Methylene chloride	8	5	3	0
Styrene	8	8	0	0
Tetrachloroethene	8	8	0	0
Toluene	8	2	6	0
Total Xylene	8	0	0	8
trans-1,2-Dichloroethene	8	8	0	0
trans-1,3-Dichloropropene	8	8	0	0
trans-1,4-Dichloro-2-butene	8	8	0	0

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Trichloroethene	8	8	0	0
Trichlorofluoromethane	8	8	0	0
Vinyl acetate	8	8	0	0
Vinyl chloride	8	7	1	0
Total	408	356	40	12

Samples were analyzed using EPA Method 8260B (B)

**TABLE 5-17. VOLATILE ORGANIC COMPOUNDS (VOCs) IN LEACHATE
AALB 7.4A, MARCH 20, 2002 THROUGH DECEMBER 16, 2002**

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,1,1,2-Tetrachloroethane	4	4	0	0
1,1,1-Trichloroethane	4	4	0	0
1,1,2,2-Tetrachloroethane	4	4	0	0
1,1,2-Trichloroethane	4	4	0	0
1,1-Dichloroethane	4	4	0	0
1,1-Dichloroethene	4	4	0	0
1,2,3-Trichloropropane	4	4	0	0
1,2-Dibromo-3-Chloropropane	4	4	0	0
1,2-Dibromoethane	4	4	0	0
1,2-Dichlorobenzene	4	4	0	0
1,2-Dichlorobenzene	4	4	0	0
1,2-Dichloropropane	4	4	0	0
1,4-Dichlorobenzene	4	4	0	0
2-Chloroethylvinyl ether	4	4	0	0
2-Hexanone	4	4	0	0
Acetone	4	1	0	3
Acrolein	4	4	0	0
Acrylonitrile	4	4	0	0
Benzene	4	3	1	0
Bromochloromethane	4	4	0	0
Bromoform	4	4	0	0
Bromomethane	4	4	0	0
Carbon Disulfide	4	4	0	0
Carbon Tetrachloride	4	4	0	0
Chlorobenzene	4	4	0	0
Chloroethane	4	4	0	0
Chloroform	4	4	0	0
Chloromethane	4	4	0	0
cis-1,2-Dichloroethene	4	4	0	0
cis-1,3-Dichloropropene	4	4	0	0
Dibromochloromethane	4	4	0	0
Dibromomethane	4	4	0	0
Dichlorobromomethane	4	4	0	0
Dichlorodifluoromethane	4	4	0	0
Ethyl methacrylate	4	4	0	0

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Ethylbenzene	4	0	4	0
Iodomethane	4	4	0	0
Methyl Ethyl Ketone	4	1	0	3
Methyl Isobutyl Ketone	4	0	2	2
Methylene chloride	4	3	1	0
Styrene	4	4	0	0
Tetrachloroethene	4	4	0	0
Toluene	4	0	2	2
Total Xylene	4	0	3	1
trans-1,2-Dichloroethene	4	4	0	0
trans-1,3-Dichloropropene	4	4	0	0
trans-1,4-Dichloro-2-butene	4	4	0	0
Trichloroethene	4	4	0	0
Trichlorofluoromethane	4	4	0	0
Vinyl acetate	4	4	0	0
Vinyl chloride	4	2	2	0
Total	204	178	15	11

Samples were analyzed using EPA Method 8260B (B)

TABLE 5-18. VOLATILE ORGANIC COMPOUNDS (VOCs) IN LEACHATE AALB-7.4B, MARCH 20, 2002 THROUGH DECEMBER 16, 2002

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,1,1,2-Tetrachloroethane	6	6	0	0
1,1,1-Trichloroethane	6	6	0	0
1,1,2,2-Tetrachloroethane	6	6	0	0
1,1,2-Trichloroethane	6	6	0	0
1,1-Dichloroethane	6	6	0	0
1,1-Dichloroethene	6	6	0	0
1,2,3-Trichloropropane	6	6	0	0
1,2-Dibromo-3-Chloropropane DBCP	6	6	0	0
1,2-Dibromoethane (EDB)	6	6	0	0
1,2-Dichlorobenzene	6	6	0	0
1,2-Dichlorobenzene	6	6	0	0
1,2-Dichloropropane	6	6	0	0
1,4-Dichlorobenzene	6	5	1	0
2-Chloroethylvinyl ether	6	6	0	0
2-Hexanone	6	6	0	0
Acetone	6	0	0	6
Acrolein	6	6	0	0
Acrylonitrile	6	6	0	0
Benzene	6	2	4	0
Bromochloromethane	6	6	0	0
Bromoform	6	6	0	0
Bromomethane	6	6	0	0
Carbon Disulfide	6	6	0	0
Carbon Tetrachloride	6	6	0	0

VOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Chlorobenzene	6	6	0	0
Chloroethane	6	6	0	0
Chloroform	6	6	0	0
Chloromethane	6	6	0	0
cis-1,2-Dichloroethene	6	6	0	0
cis-1,3-Dichloropropene	6	6	0	0
Dibromochloromethane	6	6	0	0
Dibromomethane	6	6	0	0
Dichlorobromomethane	6	6	0	0
Dichlorodifluoromethane	6	6	0	0
Ethyl methacrylate	6	6	0	0
Ethylbenzene	6	0	6	0
Iodomethane	6	6	0	0
Methyl Ethyl Ketone	6	0	0	6
Methyl Isobutyl Ketone	6	0	1	5
Methylene chloride	6	2	4	0
Styrene	6	5	1	0
Tetrachloroethene	6	6	0	0
Toluene	6	0	0	6
Total Xylene	6	0	1	5
trans-1,2-Dichloroethene	6	6	0	0
trans-1,3-Dichloropropene	6	6	0	0
trans-1,4-Dichloro-2-butene	6	6	0	0
Trichloroethene	6	5	1	0
Trichlorofluoromethane	6	6	0	0
Vinyl acetate	6	6	0	0
Vinyl chloride	6	2	4	0
Total	306	261	23	22

Samples were analyzed using EPA Method 8260B (B)

Summary of Leachate Semi-Volatile Organic Compounds (SVOCs)

Tables 5-19 through 5-24 provide a summary of the semi-volatile organic compounds (SVOCs) in leachate. Detection frequency tables showing the SVOC compounds that were analyzed using EPA Method 8270.

Common constituents for the three units of study include diethyl phthalate, phenol, 1,4-dioxane, naphthalene, cresol, m, o and p. Approximately 1 percent of the samples had concentrations within the 1.0-100 ug/l range. Less than 1 percent of the samples were at concentrations greater than 100 ug/l.

**TABLE 5-19. SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCs) IN LEACHATE
CONTROL 7.3A, JUNE 26, 2001 THROUGH DECEMBER 16, 2002**

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
0,0,0-Triethylphosphorothioate	8	8	0	0
1,2,4,5-Tetrachlorobenzene	8	8	0	0
1,2,4-Trichlorobenzene	8	8	0	0
1,2-Dichlorobenzene	8	8	0	0
1,3-Dichlorobenzene	8	8	0	0
1,4-Dichlorobenzene	8	3	5	0
1,4-Dioxane	8	6	2	0
1,4-Naphthoquinone	8	8	0	0
1-Naphthylamine	8	8	0	0
2,2'-Oxybis(1-Chloropropane)	8	8	0	0
2,3,4,6-Tetrachlorophenol	8	8	0	0
2,4,5-Trichlorophenol	8	8	0	0
2,4,6-Trichlorophenol	8	8	0	0
2,4-Dichlorophenol	8	8	0	0
2,4-Dimethylphenol	8	6	2	0
2,4-Dinitrophenol	8	8	0	0
2,4-Dinitrotoluene	8	8	0	0
2,6-Dichlorophenol	8	8	0	0
2,6-Dinitrotoluene	8	8	0	0
2-Acetylaminofluorene	8	8	0	0
2-Chloronaphthalene	8	8	0	0
2-Chlorophenol	8	8	0	0
2-Methylnaphthalene	8	8	0	0
2-Naphthylamine	8	8	0	0
2-Nitroaniline	8	8	0	0
2-Nitrophenol	8	8	0	0
2-sec-Butyl-4,6-dinitrophenol	8	8	0	0
3,3'-Dichlorobenzidine	8	8	0	0
3,3'-Dimethylbenzidine	8	8	0	0
3-Methylcholanthrene	8	8	0	0
3-Nitroaniline	8	8	0	0
4-Aminobiphenyl	8	8	0	0
4-Bromophenyl phenyl ether	8	8	0	0
4-Chloroaniline	8	8	0	0
4-Chlorophenyl phenyl ether	8	8	0	0
4-Nitroaniline	8	8	0	0
4-Nitrophenol	8	8	0	0
5-Nitro-o-toluidine	8	8	0	0
7,12-Dimethylbenz(a)anthracene	8	8	0	0
Acenaphthene	8	8	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Acenaphthylene	8	8	0	0
Acetophenone	8	8	0	0
Anthracene	8	8	0	0
Benzo(a)anthracene	8	8	0	0
Benzo(a)pyrene	8	8	0	0
Benzo(b)fluoranthene	8	8	0	0
Benzo(ghi)perylene	8	8	0	0
Benzo(k)fluoranthene	8	8	0	0
Benzyl alcohol	8	6	0	2
Bis(2-chloroethoxy) methane	8	8	0	0
Bis(2-chloroethyl) ether	8	8	0	0
Bis(2-ethylhexyl) phthalate	8	7	1	0
Butyl benzyl phthalate	8	8	0	0
Chlorobenzilate	8	8	0	0
Chrysene	8	8	0	0
Cresol, 4,6-Dinitro-O-	8	8	0	0
Cresol, m-	8	6	0	2
Cresol, o-	8	8	0	0
Cresol, p-	8	6	0	2
Cresol, p-Chloro-m-	8	8	0	0
Diallate	8	8	0	0
Dibenzo(a,h)anthracene	8	8	0	0
Dibenzofuran	8	8	0	0
Diethyl phthalate	8	7	1	0
Dimethoate	8	8	0	0
Dimethyl phthalate	8	8	0	0
Di-n-butyl phthalate	8	8	0	0
Di-n-octyl phthalate	8	8	0	0
Diphenylamine	8	8	0	0
Disulfoton	8	8	0	0
Ethyl methane sulfonate	8	8	0	0
Famphur	8	8	0	0
Fluoranthene	8	8	0	0
Fluorene	8	8	0	0
Hexachlorobenzene	8	8	0	0
Hexachlorobutadiene	8	8	0	0
Hexachlorocyclopentadiene	8	8	0	0
Hexachloroethane	8	8	0	0
Hexachloropropene	8	8	0	0
Indeno(1,2,3-cd)pyrene	8	8	0	0
Isodrin	8	8	0	0
Isophorone	8	8	0	0
Isosafrole	8	8	0	0
Kepone	8	8	0	0
m-Dinitrobenzene	8	8	0	0
Methapyrilene	8	8	0	0
Methyl methanesulfonate	8	8	0	0
Methyl parathion	8	8	0	0
Naphthalene	8	8	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Nitrobenzene	8	8	0	0
N-Nitrosodiethylamine	8	8	0	0
N-Nitrosodimethylamine	8	8	0	0
N-Nitrosodi-n-butylamine	8	8	0	0
N-Nitroso-Di-n-propylamine	8	8	0	0
N-nitrosodiphenylamine	8	8	0	0
N-Nitrosomethylethylamine	8	8	0	0
N-Nitrosopiperidine	8	8	0	0
N-Nitrosopyrrolidine	8	8	0	0
o-Toluidine	8	8	0	0
Parathion	8	8	0	0
p-Dimethylaminoazobenzene	8	8	0	0
Pentachlorobenzene	8	8	0	0
Pentachloronitrobenzene	8	8	0	0
Pentachlorophenol	8	8	0	0
Phenacetin	8	8	0	0
Phenanthrene	8	8	0	0
Phenol	8	6	2	0
Phorate	8	8	0	0
p-Phenylenediamine	8	8	0	0
Pronamide	8	8	0	0
Pyrene	8	8	0	0
Safrole	8	8	0	0
Sym-Trinitrobenzene	8	8	0	0
Thionazin	8	8	0	0
Total	456	443	7	6

Samples were analyzed using EPA Method 8270

TABLE 5-20. SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCS) IN LEACHATE: CONTROL 7.3B, JUNE 26, 2001 THROUGH DECEMBER 16, 2003

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
0,0,0-Triethylphosphorothioate	7	7	0	0
1,2,4,5-Tetrachlorobenzene	7	7	0	0
1,2,4-Trichlorobenzene	7	7	0	0
1,2-Dichlorobenzene	7	7	0	0
1,3-Dichlorobenzene	7	7	0	0
1,4-Dichlorobenzene	7	3	4	0
1,4-Dioxane	7	7	0	0
1,4-Naphthoquinone	7	7	0	0
1-Naphthylamine	7	7	0	0
2,2'-Oxybis(1-Chloropropane)	7	7	0	0
2,3,4,6-Tetrachlorophenol	7	7	0	0
2,4,5-Trichlorophenol	7	7	0	0
2,4,6-Trichlorophenol	7	7	0	0
2,4-Dichlorophenol	7	7	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
2,4-Dimethylphenol	7	7	0	0
2,4-Dinitrophenol	7	7	0	0
2,4-Dinitrotoluene	7	7	0	0
2,6-Dichlorophenol	7	7	0	0
2,6-Dinitrotoluene	7	7	0	0
2-Acetylaminofluorene	7	7	0	0
2-Chloronaphthalene	7	7	0	0
2-Chlorophenol	7	7	0	0
2-Methylnaphthalene	7	7	0	0
2-Naphthylamine	7	7	0	0
2-Nitroaniline	7	7	0	0
2-Nitrophenol	7	7	0	0
2-sec-Butyl-4,6-dinitrophenol	7	7	0	0
3,3'-Dichlorobenzidine	7	7	0	0
3,3'-Dimethylbenzidine	7	7	0	0
3-Methylcholanthrene	7	7	0	0
3-Nitroaniline	7	7	0	0
4-Aminobiphenyl	7	7	0	0
4-Bromophenyl phenyl ether	7	7	0	0
4-Chloroaniline	7	7	0	0
4-Chlorophenyl phenyl ether	7	7	0	0
4-Nitroaniline	7	7	0	0
4-Nitrophenol	7	7	0	0
5-Nitro-o-toluidine	7	7	0	0
7,12-Dimethylbenz(a)anthracene	7	7	0	0
Acenaphthene	7	7	0	0
Acenaphthylene	7	7	0	0
Acetophenone	7	7	0	0
Anthracene	7	7	0	0
Benzo(a)anthracene	7	7	0	0
Benzo(a)pyrene	7	7	0	0
Benzo(b)fluoranthene	7	7	0	0
Benzo(ghi)perylene	7	7	0	0
Benzo(k)fluoranthene	7	7	0	0
Benzyl alcohol	7	7	0	0
Bis(2-chloroethoxy) methane	7	7	0	0
Bis(2-chloroethyl) ether	7	7	0	0
Bis(2-ethylhexyl) phthalate	7	6	1	0
Butyl benzyl phthalate	7	7	0	0
Chlorobenzilate	7	7	0	0
Chrysene	7	7	0	0
Cresol, 4,6-Dinitro-O-	7	7	0	0
Cresol, m-	7	7	0	0
Cresol, o-	7	7	0	0
Cresol, p-	7	6	1	0
Cresol, p-Chloro-m-	7	7	0	0
Diallate	7	7	0	0
Dibenzo(a,h)anthracene	7	7	0	0
Dibenzofuran	7	7	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Diethyl phthalate	7	4	3	0
Dimethoate	7	7	0	0
Dimethyl phthalate	7	7	0	0
Di-n-butyl phthalate	7	7	0	0
Di-n-octyl phthalate	7	7	0	0
Diphenylamine	7	7	0	0
Disulfoton	7	7	0	0
Ethyl methane sulfonate	7	7	0	0
Famphur	7	7	0	0
Fluoranthene	7	7	0	0
Fluorene	7	7	0	0
Hexachlorobenzene	7	7	0	0
Hexachlorobutadiene	7	7	0	0
Hexachlorocyclopentadiene	7	7	0	0
Hexachloroethane	7	7	0	0
Hexachloropropene	7	7	0	0
Indeno(1,2,3-cd)pyrene	7	7	0	0
Isodrin	7	7	0	0
Isophorone	7	7	0	0
Isosafrole	7	7	0	0
Kepone	7	7	0	0
m-Dinitrobenzene	7	7	0	0
Methapyrilene	7	7	0	0
Methyl methanesulfonate	7	7	0	0
Methyl parathion	7	7	0	0
Naphthalene	7	7	0	0
Nitrobenzene	7	7	0	0
N-Nitrosodiethylamine	7	7	0	0
N-Nitrosodimethylamine	7	7	0	0
N-Nitrosodi-n-butylamine	7	7	0	0
N-Nitroso-Di-n-propylamine	7	7	0	0
N-nitrosodiphenylamine	7	7	0	0
N-Nitrosomethylethylamine	7	7	0	0
N-Nitrosopiperidine	7	7	0	0
N-Nitrosopyrrolidine	7	7	0	0
o-Toluidine	7	7	0	0
Parathion	7	7	0	0
p-Dimethylaminoazobenzene	7	7	0	0
Pentachlorobenzene	7	7	0	0
Pentachloronitrobenzene	7	7	0	0
Pentachlorophenol	7	7	0	0
Phenacetin	7	7	0	0
Phenanthrene	7	7	0	0
Phenol	7	6	1	0
Phorate	7	7	0	0
p-Phenylenediamine	7	7	0	0
Pronamide	7	7	0	0
Pyrene	7	7	0	0
Safrole	7	7	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Sym-Trinitrobenzene	7	7	0	0
Thionazin	7	7	0	0
Total	798	788	10	0

Samples were analyzed using EPA Method 8270

**TABLE 5-21. SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCs) IN LEACHATE
FLB 5.1A, JUNE 1, 2001 THROUGH DECEMBER 16, 2002**

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
0,0,0-Triethylphosphorothioate	9	9	0	0
1,2,4,5-Tetrachlorobenzene	9	9	0	0
1,2,4-Trichlorobenzene	9	9	0	0
1,2-Dichlorobenzene	9	9	0	0
1,3-Dichlorobenzene	9	9	0	0
1,4-Dichlorobenzene	9	9	0	0
1,4-Dioxane	9	4	4	1
1,4-Naphthoquinone	9	9	0	0
1-Naphthylamine	9	9	0	0
2,2'-Oxybis(1-Chloropropane)	9	9	0	0
2,3,4,6-Tetrachlorophenol	9	9	0	0
2,4,5-Trichlorophenol	9	9	0	0
2,4,6-Trichlorophenol	9	9	0	0
2,4-Dichlorophenol	9	9	0	0
2,4-Dimethylphenol	9	8	1	0
2,4-Dinitrophenol	9	9	0	0
2,4-Dinitrotoluene	9	9	0	0
2,6-Dichlorophenol	9	9	0	0
2,6-Dinitrotoluene	9	9	0	0
2-Acetylaminofluorene	9	9	0	0
2-Chloronaphthalene	9	9	0	0
2-Chlorophenol	9	9	0	0
2-Methylnaphthalene	9	9	0	0
2-Naphthylamine	9	9	0	0
2-Nitroaniline	9	9	0	0
2-Nitrophenol	9	9	0	0
2-sec-Butyl-4,6-dinitrophenol	9	9	0	0
3,3'-Dichlorobenzidine	9	9	0	0
3,3'-Dimethylbenzidine	9	9	0	0
3-Methylcholanthrene	9	9	0	0
3-Nitroaniline	9	9	0	0
4-Aminobiphenyl	9	9	0	0
4-Bromophenyl phenyl ether	9	9	0	0
4-Chloroaniline	9	9	0	0
4-Chlorophenyl phenyl ether	9	9	0	0
4-Nitroaniline	9	9	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
4-Nitrophenol	9	9	0	0
5-Nitro-o-toluidine	9	9	0	0
7,12-Dimethylbenz(a)anthracene	9	9	0	0
Acenaphthene	9	9	0	0
Acenaphthylene	9	9	0	0
Acetophenone	9	9	0	0
Anthracene	9	9	0	0
Benzo(a)anthracene	9	9	0	0
Benzo(a)pyrene	9	9	0	0
Benzo(b)fluoranthene	9	9	0	0
Benzo(ghi)perylene	9	9	0	0
Benzo(k)fluoranthene	9	9	0	0
Benzyl alcohol	9	9	0	0
Bis(2-chloroethoxy) methane	9	9	0	0
Bis(2-chloroethyl) ether	9	9	0	0
Bis(2-ethylhexyl) phthalate	9	8	0	1
Butyl benzyl phthalate	9	9	0	0
Chlorobenzilate	9	9	0	0
Chrysene	9	9	0	0
Cresol, 4,6-Dinitro-O-	9	9	0	0
Cresol, m-	9	6	1	2
Cresol, o-	9	9	0	0
Cresol, p-	9	6	1	2
Cresol, p-Chloro-m-	9	9	0	0
Diallate	9	9	0	0
Dibenzo(a,h)anthracene	9	9	0	0
Dibenzofuran	9	9	0	0
Diethyl phthalate	9	9	0	0
Dimethoate	9	9	0	0
Dimethyl phthalate	9	9	0	0
Di-n-butyl phthalate	9	9	0	0
Di-n-octyl phthalate	9	9	0	0
Diphenylamine	9	9	0	0
Disulfoton	9	9	0	0
Ethyl methane sulfonate	9	9	0	0
Famphur	9	9	0	0
Fluoranthene	9	9	0	0
Fluorene	9	9	0	0
Hexachlorobenzene	9	9	0	0
Hexachlorobutadiene	9	9	0	0
Hexachlorocyclopentadiene	9	9	0	0
Hexachloroethane	9	9	0	0
Hexachloropropene	9	9	0	0
Indeno(1,2,3-cd)pyrene	9	9	0	0
Isodrin	9	9	0	0
Isophorone	9	9	0	0
Isosafrole	9	9	0	0
Kepone	9	9	0	0
m-Dinitrobenzene	9	9	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Methapyrilene	9	9	0	0
Methyl methanesulfonate	9	9	0	0
Methyl parathion	9	9	0	0
Naphthalene	9	6	3	0
Nitrobenzene	9	9	0	0
N-Nitrosodiethylamine	9	9	0	0
N-Nitrosodimethylamine	9	9	0	0
N-Nitrosodi-n-butylamine	9	9	0	0
N-Nitroso-Di-n-propylamine	9	9	0	0
N-nitrosodiphenylamine	9	9	0	0
N-Nitrosomethylethylamine	9	9	0	0
N-Nitrosopiperidine	9	9	0	0
N-Nitrosopyrrolidine	9	9	0	0
o-Toluidine	9	7	2	0
Parathion	9	9	0	0
p-Dimethylaminoazobenzene	9	9	0	0
Pentachlorobenzene	9	9	0	0
Pentachloronitrobenzene	9	9	0	0
Pentachlorophenol	9	9	0	0
Phenacetin	9	9	0	0
Phenanthrene	9	9	0	0
Phenol	9	7	2	0
Phorate	9	9	0	0
p-Phenylenediamine	9	9	0	0
Pronamide	9	9	0	0
Pyrene	9	9	0	0
Safrole	9	9	0	0
Sym-Trinitrobenzene	9	9	0	0
Thionazin	9	9	0	0
Total	1026	1006	14	6

Samples were analyzed using EPA Method 8270

TABLE 5-22. SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCs) IN LEACHATE FLB 5.2B, JUNE 1, 2001 THROUGH DECEMBER 16, 2002

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
0,0,0-Triethylphosphorothioate	8	8	0	0
1,2,4,5-Tetrachlorobenzene	8	8	0	0
1,2,4-Trichlorobenzene	8	8	0	0
1,2-Dichlorobenzene	8	8	0	0
1,3-Dichlorobenzene	8	8	0	0
1,4-Dichlorobenzene	8	6	2	0
1,4-Dioxane	8	2	6	0
1,4-Naphthoquinone	8	8	0	0
1-Naphthylamine	8	8	0	0
2,2'-Oxybis(1-Chloropropane)	8	8	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
2,3,4,6-Tetrachlorophenol	8	8	0	0
2,4,5-Trichlorophenol	8	8	0	0
2,4,6-Trichlorophenol	8	8	0	0
2,4-Dichlorophenol	8	8	0	0
2,4-Dimethylphenol	8	8	0	0
2,4-Dinitrophenol	8	8	0	0
2,4-Dinitrotoluene	8	8	0	0
2,6-Dichlorophenol	8	8	0	0
2,6-Dinitrotoluene	8	8	0	0
2-Acetylaminofluorene	8	8	0	0
2-Chloronaphthalene	8	8	0	0
2-Chlorophenol	8	8	0	0
2-Methylnaphthalene	8	8	0	0
2-Naphthylamine	8	8	0	0
2-Nitroaniline	8	8	0	0
2-Nitrophenol	8	8	0	0
2-sec-Butyl-4,6-dinitrophenol	8	8	0	0
3,3'-Dichlorobenzidine	8	8	0	0
3,3'-Dimethylbenzidine	8	8	0	0
3-Methylcholanthrene	8	8	0	0
3-Nitroaniline	8	8	0	0
4-Aminobiphenyl	8	8	0	0
4-Bromophenyl phenyl ether	8	8	0	0
4-Chloroaniline	8	8	0	0
4-Chlorophenyl phenyl ether	8	8	0	0
4-Nitroaniline	8	8	0	0
4-Nitrophenol	8	8	0	0
5-Nitro-o-toluidine	8	8	0	0
7,12-Dimethylbenz(a)anthracene	8	8	0	0
Acenaphthene	8	8	0	0
Acenaphthylene	8	8	0	0
Acetophenone	8	8	0	0
Anthracene	8	8	0	0
Benzo(a)anthracene	8	8	0	0
Benzo(a)pyrene	8	8	0	0
Benzo(b)fluoranthene	8	8	0	0
Benzo(ghi)perylene	8	8	0	0
Benzo(k)fluoranthene	8	8	0	0
Benzyl alcohol	8	8	0	0
Bis(2-chloroethoxy) methane	8	8	0	0
Bis(2-chloroethyl) ether	8	8	0	0
Bis(2-ethylhexyl) phthalate	8	7	1	0
Butyl benzyl phthalate	8	8	0	0
Chlorobenzilate	8	8	0	0
Chrysene	8	8	0	0
Cresol, 4,6-Dinitro-O-	8	8	0	0
Cresol, m-	8	5	2	1
Cresol, o-	8	8	0	0
Cresol, p-	8	5	2	1

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Cresol, p-Chloro-m-	8	8	0	0
Diallate	8	8	0	0
Dibenzo(a,h)anthracene	8	8	0	0
Dibenzofuran	8	8	0	0
Diethyl phthalate	8	8	0	0
Dimethoate	8	8	0	0
Dimethyl phthalate	8	8	0	0
Di-n-butyl phthalate	8	8	0	0
Di-n-octyl phthalate	8	8	0	0
Diphenylamine	8	8	0	0
Disulfoton	8	8	0	0
Ethyl methane sulfonate	8	8	0	0
Famphur	8	8	0	0
Fluoranthene	8	8	0	0
Fluorene	8	8	0	0
Hexachlorobenzene	8	8	0	0
Hexachlorobutadiene	8	8	0	0
Hexachlorocyclopentadiene	8	8	0	0
Hexachloroethane	8	8	0	0
Hexachloropropene	8	8	0	0
Indeno(1,2,3-cd)pyrene	8	8	0	0
Isodrin	8	8	0	0
Isophorone	8	8	0	0
Isosafrole	8	8	0	0
Kepone	8	8	0	0
m-Dinitrobenzene	8	8	0	0
Methapyrilene	8	8	0	0
Methyl methanesulfonate	8	8	0	0
Methyl parathion	8	8	0	0
Naphthalene	8	8	0	0
Nitrobenzene	8	8	0	0
N-Nitrosodiethylamine	8	8	0	0
N-Nitrosodimethylamine	8	8	0	0
N-Nitrosodi-n-butylamine	8	8	0	0
N-Nitroso-Di-n-propylamine	8	8	0	0
N-nitrosodiphenylamine	8	8	0	0
N-Nitrosomethylethylamine	8	8	0	0
N-Nitrosopiperidine	8	8	0	0
N-Nitrosopyrrolidine	8	8	0	0
o-Toluidine	8	5	3	0
Parathion	8	8	0	0
p-Dimethylaminoazobenzene	8	8	0	0
Pentachlorobenzene	8	8	0	0
Pentachloronitrobenzene	8	8	0	0
Pentachlorophenol	8	8	0	0
Phenacetin	8	8	0	0
Phenanthrene	8	8	0	0
Phenol	8	7	1	0
Phorate	8	8	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
p-Phenylenediamine	8	8	0	0
Pronamide	8	8	0	0
Pyrene	8	8	0	0
Safrole	8	8	0	0
Sym-Trinitrobenzene	8	8	0	0
Thionazin	8	8	0	0
Total	912	893	17	2

Samples were analyzed using EPA Method 8270

TABLE 5-23. SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCs) IN LEACHATE AALB 7.4A, MARCH 20, 2002 THROUGH DECEMBER 16, 2002

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
0,0,0-Triethylphosphorothioate	4	4	0	0
1,2,4,5-Tetrachlorobenzene	4	4	0	0
1,2,4-Trichlorobenzene	4	4	0	0
1,2-Dichlorobenzene	4	4	0	0
1,3-Dichlorobenzene	4	4	0	0
1,4-Dichlorobenzene	4	4	0	0
1,4-Dioxane	4	4	0	0
1,4-Naphthoquinone	4	4	0	0
1-Naphthylamine	4	4	0	0
2,2'-Oxybis(1-Chloropropane)	4	4	0	0
2,3,4,6-Tetrachlorophenol	4	4	0	0
2,4,5-Trichlorophenol	4	4	0	0
2,4,6-Trichlorophenol	4	4	0	0
2,4-Dichlorophenol	4	4	0	0
2,4-Dimethylphenol	4	4	0	0
2,4-Dinitrophenol	4	4	0	0
2,4-Dinitrotoluene	4	4	0	0
2,6-Dichlorophenol	4	4	0	0
2,6-Dinitrotoluene	4	4	0	0
2-Acetylaminofluorene	4	4	0	0
2-Chloronaphthalene	4	4	0	0
2-Chlorophenol	4	4	0	0
2-Methylnaphthalene	4	4	0	0
2-Naphthylamine	4	4	0	0
2-Nitroaniline	4	4	0	0
2-Nitrophenol	4	4	0	0
2-sec-Butyl-4,6-dinitrophenol	4	4	0	0
3,3'-Dichlorobenzidine	4	4	0	0
3,3'-Dimethylbenzidine	4	4	0	0
3-Methylcholanthrene	4	4	0	0
3-Nitroaniline	4	4	0	0
4-Aminobiphenyl	4	4	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
4-Bromophenyl phenyl ether	4	4	0	0
4-Chloroaniline	4	4	0	0
4-Chlorophenyl phenyl ether	4	4	0	0
4-Nitroaniline	4	4	0	0
4-Nitrophenol	4	4	0	0
5-Nitro-o-toluidine	4	4	0	0
7,12-Dimethylbenz(a)anthracene	4	4	0	0
Acenaphthene	4	4	0	0
Acenaphthylene	4	4	0	0
Acetophenone	4	4	0	0
Anthracene	4	4	0	0
Benzo(a)anthracene	4	4	0	0
Benzo(a)pyrene	4	4	0	0
Benzo(b)fluoranthene	4	4	0	0
Benzo(ghi)perylene	4	4	0	0
Benzo(k)fluoranthene	4	4	0	0
Benzyl alcohol	4	4	0	0
Bis(2-chloroethoxy) methane	4	4	0	0
Bis(2-chloroethyl) ether	4	4	0	0
Bis(2-ethylhexyl) phthalate	4	3	1	0
Butyl benzyl phthalate	4	4	0	0
Chlorobenzilate	4	4	0	0
Chrysene	4	4	0	0
Cresol, 4,6-Dinitro-O-	4	4	0	0
Cresol, m-	4	1	0	3
Cresol, o-	4	2	2	0
Cresol, p-	4	0	1	3
Cresol, p-Chloro-m-	4	4	0	0
Diallate	4	4	0	0
Dibenzo(a,h)anthracene	4	4	0	0
Dibenzofuran	4	4	0	0
Diethyl phthalate	4	4	0	0
Dimethoate	4	4	0	0
Dimethyl phthalate	4	4	0	0
Di-n-butyl phthalate	4	4	0	0
Di-n-octyl phthalate	4	4	0	0
Diphenylamine	4	4	0	0
Disulfoton	4	4	0	0
Ethyl methane sulfonate	4	4	0	0
Famphur	4	4	0	0
Fluoranthene	4	4	0	0
Fluorene	4	4	0	0
Hexachlorobenzene	4	4	0	0
Hexachlorobutadiene	4	4	0	0
Hexachlorocyclopentadiene	4	4	0	0
Hexachloroethane	4	4	0	0
Hexachloropropene	4	4	0	0
Indeno(1,2,3-cd)pyrene	4	4	0	0
Isodrin	4	4	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Isophorone	4	4	0	0
Isosafrole	4	4	0	0
Kepone	4	4	0	0
m-Dinitrobenzene	4	4	0	0
Methapyrilene	4	4	0	0
Methyl methanesulfonate	4	4	0	0
Methyl parathion	4	4	0	0
Naphthalene	4	4	0	0
Nitrobenzene	4	4	0	0
N-Nitrosodiethylamine	4	4	0	0
N-Nitrosodimethylamine	4	4	0	0
N-Nitrosodi-n-butylamine	4	4	0	0
N-Nitroso-Di-n-propylamine	4	4	0	0
N-nitrosodiphenylamine	4	4	0	0
N-Nitrosomethylethylamine	4	4	0	0
N-Nitrosopiperidine	4	4	0	0
N-Nitrosopyrrolidine	4	4	0	0
o-Toluidine	4	3	1	0
Parathion	4	4	0	0
p-Dimethylaminoazobenzene	4	4	0	0
Pentachlorobenzene	4	4	0	0
Pentachloronitrobenzene	4	4	0	0
Pentachlorophenol	4	4	0	0
Phenacetin	4	4	0	0
Phenanthrene	4	4	0	0
Phenol	4	2	2	0
Phorate	4	4	0	0
p-Phenylenediamine	4	4	0	0
Pronamide	4	4	0	0
Pyrene	4	4	0	0
Safrole	4	4	0	0
Sym-Trinitrobenzene	4	4	0	0
Thionazin	4	4	0	0
Total	456	443	7	6

Samples were analyzed using EPA Method 8270

TABLE 5-24. SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCs) IN LEACHATE: AALB 7.4B, MARCH 20, 2002 THROUGH DECEMBER 16, 2002

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
0,0,0-Triethylphosphorothioate	4	4	0	0
1,2,4,5-Tetrachlorobenzene	4	4	0	0
1,2,4-Trichlorobenzene	4	4	0	0
1,2-Dichlorobenzene	4	4	0	0
1,3-Dichlorobenzene	4	4	0	0
1,4-Dichlorobenzene	4	4	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
1,4-Dioxane	4	4	0	0
1,4-Naphthoquinone	4	4	0	0
1-Naphthylamine	4	4	0	0
2,2'-Oxybis(1-Chloropropane)	4	4	0	0
2,3,4,6-Tetrachlorophenol	4	4	0	0
2,4,5-Trichlorophenol	4	4	0	0
2,4,6-Trichlorophenol	4	4	0	0
2,4-Dichlorophenol	4	4	0	0
2,4-Dimethylphenol	4	4	0	0
2,4-Dinitrophenol	4	4	0	0
2,4-Dinitrotoluene	4	4	0	0
2,6-Dichlorophenol	4	4	0	0
2,6-Dinitrotoluene	4	4	0	0
2-Acetylaminofluorene	4	4	0	0
2-Chloronaphthalene	4	4	0	0
2-Chlorophenol	4	4	0	0
2-Methylnaphthalene	4	4	0	0
2-Naphthylamine	4	4	0	0
2-Nitroaniline	4	4	0	0
2-Nitrophenol	4	4	0	0
2-sec-Butyl-4,6-dinitrophenol	4	4	0	0
3,3'-Dichlorobenzidine	4	4	0	0
3,3'-Dimethylbenzidine	4	4	0	0
3-Methylcholanthrene	4	4	0	0
3-Nitroaniline	4	4	0	0
4-Aminobiphenyl	4	4	0	0
4-Bromophenyl phenyl ether	4	4	0	0
4-Chloroaniline	4	4	0	0
4-Chlorophenyl phenyl ether	4	4	0	0
4-Nitroaniline	4	4	0	0
4-Nitrophenol	4	4	0	0
5-Nitro-o-toluidine	4	4	0	0
7,12-Dimethylbenz(a)anthracene	4	4	0	0
Acenaphthene	4	4	0	0
Acenaphthylene	4	4	0	0
Acetophenone	4	4	0	0
Anthracene	4	4	0	0
Benzo(a)anthracene	4	4	0	0
Benzo(a)pyrene	4	4	0	0
Benzo(b)fluoranthene	4	4	0	0
Benzo(ghi)perylene	4	4	0	0
Benzo(k)fluoranthene	4	4	0	0
Benzyl alcohol	4	4	0	0
Bis(2-chloroethoxy) methane	4	4	0	0
Bis(2-chloroethyl) ether	4	4	0	0
Bis(2-ethylhexyl) phthalate	4	3	1	0
Butyl benzyl phthalate	4	4	0	0
Chlorobenzilate	4	4	0	0
Chrysene	4	4	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Cresol, 4,6-Dinitro-O-	4	4	0	0
Cresol, m-	4	0	0	4
Cresol, o-	4	2	0	2
Cresol, p-	4	0	0	4
Cresol, p-Chloro-m-	4	4	0	0
Diallate	4	4	0	0
Dibenzo(a,h)anthracene	4	4	0	0
Dibenzofuran	4	3	1	0
Diethyl phthalate	4	4	0	0
Dimethoate	4	4	0	0
Dimethyl phthalate	4	4	0	0
Di-n-butyl phthalate	4	4	0	0
Di-n-octyl phthalate	4	4	0	0
Diphenylamine	4	4	0	0
Disulfoton	4	4	0	0
Ethyl methane sulfonate	4	4	0	0
Famphur	4	4	0	0
Fluoranthene	4	4	0	0
Fluorene	4	4	0	0
Hexachlorobenzene	4	4	0	0
Hexachlorobutadiene	4	4	0	0
Hexachlorocyclopentadiene	4	4	0	0
Hexachloroethane	4	4	0	0
Hexachloropropene	4	4	0	0
Indeno(1,2,3-cd)pyrene	4	4	0	0
Isodrin	4	4	0	0
Isophorone	4	4	0	0
Isosafrole	4	4	0	0
Kepone	4	4	0	0
m-Dinitrobenzene	4	4	0	0
Methapyrilene	4	4	0	0
Methyl methanesulfonate	4	4	0	0
Methyl parathion	4	4	0	0
Naphthalene	4	3	0	1
Nitrobenzene	4	4	0	0
N-Nitrosodiethylamine	4	4	0	0
N-Nitrosodimethylamine	4	4	0	0
N-Nitrosodi-n-butylamine	4	4	0	0
N-Nitroso-Di-n-propylamine	4	4	0	0
N-nitrosodiphenylamine	4	4	0	0
N-Nitrosomethylethylamine	4	4	0	0
N-Nitrosopiperidine	4	4	0	0
N-Nitrosopyrrolidine	4	4	0	0
o-Toluidine	4	4	0	0
Parathion	4	4	0	0
p-Dimethylaminoazobenzene	4	4	0	0
Pentachlorobenzene	4	4	0	0
Pentachloronitrobenzene	4	4	0	0
Pentachlorophenol	4	4	0	0

SVOC Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1.0-100 µg/l	Number of Readings >100 µg/l
Phenacetin	4	4	0	0
Phenanthrene	4	4	0	0
Phenol	4	1	1	2
Phorate	4	4	0	0
p-Phenylenediamine	4	4	0	0
Pronamide	4	4	0	0
Pyrene	4	4	0	0
Safrole	4	4	0	0
Sym-Trinitrobenzene	4	4	0	0
Thionazin	4	4	0	0
Total	456	440	3	13

Samples were analyzed using EPA Method 8270

Summary of RCRA Hazardous Metals in Leachate

Sampling for RCRA hazardous metals, which are presented in Tables 5-25 through 5-27, were collected for all three of the study units. Sampling began for the Control and FLB units in June 2001, while sampling for the AALB began in March 2002. Samples, which are collected on a quarterly basis, are analyzed using EPA Method 6010 (B) except for mercury, which is analyzed using EPA Method 7470 (B).

For all three of the study units, potassium was detected at levels greater than 1.0 mg/l. Other common metals detected are arsenic, barium, cadmium, chromium, and lead. Ninety percent of these detected constituents were detected in ranges less than 1.0 mg/l.

**TABLE 5-25. RCRA HAZARDOUS METALS IN LEACHATE
CONTROL 7.3A AND 7.3B, JUNE 26, 2001 THROUGH DECEMBER 16, 2002**

Metals	Number of Readings	Number of Non-Detects (ND)	Number of Readings Between 0.001 - 1.0 mg/l	Number of Readings >1.0 mg/l
Arsenic, Total	14	14	0	0
Barium, Total	14	0	14	0
Cadmium, Total	14	14	0	0
Chromium, Total	14	2	12	0
Lead, Total	14	11	3	0
Potassium, Total	14	0	0	14
Selenium, Total	14	14	0	0
Silver, Total	14	14	0	0
Mercury, Total	14	14	0	0
Total	126	83	29	14

Samples were analyzed using EPA Method 6010 (B) except for mercury, which was analyzed using EPA Method 7470(B)

**TABLE 5-26. RCRA HAZARDOUS METALS IN LEACHATE
FLB 5.1A AND 5.2B, JUNE 1, 2001 THROUGH DECEMBER 16, 2002**

Metals	Number of Readings	Number of Non-Detects (ND)	Number of Readings Between 0.001 - 1.0 mg/l	Number of Readings >1.0 mg/l
Arsenic, Total	16	0	16	0
Barium, Total	16	0	11	5
Cadmium, Total	16	14	2	0
Chromium, Total	16	0	16	0
Lead, Total	16	9	7	0
Potassium, Total	16	0	0	16
Selenium, Total	16	16	0	0
Silver, Total	16	16	0	0
Mercury, Total	16	16	0	0
Total	144	71	52	21

Samples were analyzed using EPA Method 6010 (B) except for mercury, which was analyzed using EPA Method 7470(B)

**TABLE 5-27. RCRA HAZARDOUS METALS IN LEACHATE
AALB 7.4A AND 7.4B, MARCH 20, 2002 THROUGH DECEMBER 16, 2002**

Metals	Number of Readings	Number of Non-Detects (ND)	Number of Readings Between 0.001 - 1.0 mg/l	Number of Readings >1.0 mg/l
Arsenic, Total	8	0	8	0
Barium, Total	8	0	8	0
Cadmium, Total	8	2	6	0
Chromium, Total	8	0	8	0
Lead, Total	8	0	8	0
Potassium, Total	8	0	0	8
Selenium, Total	8	8	0	0
Silver, Total	8	8	0	0
Mercury, Total	8	8	0	0
Total	72	24	40	8

Samples were analyzed using EPA Method 6010 (B) except for mercury, which was analyzed using EPA Method 7470(B)

MUNICIPAL SOLID WASTE (MSW) CHARACTERISTICS

Municipal solid waste (MSW) parameters were measured both on-site using permanent monitoring probes installed at various locations in each cell on a daily basis, and by sample collection of a minimum of 30 boring samples per cell for off-site lab analysis on an annual basis. The results documented in this report apply to the Control Unit (7.3 A and B), the FLB (Unit 5.1 and 5.2) and the AALB (Unit 7.4 A and B).

Summary of Organic Solids in MSW

The organic solids have been measured for all cells under investigation. Two sampling events have occurred for each cell, the first is represented by the shaded bar and the second by the white bar in Figure 5-39. The first sampling event is referred to in the Figures as the baseline 2000/2001, and occurred at different times for the different cells. The baseline-sampling event for the FLB and Control Units occurred in June 2000. However, no waste was in place in either AALB 7.4 A or 7.4B cell, these were sampled in the summer and fall of 2001, respectively, after waste placement had commenced. The second sampling event took place in October 2002 for all cells.

Each sampling event required a minimum of 30 MSW samples to be taken per cell. Note that the two cells of the FLB (5.1 and 5.2) are each made up of two sub-cells, the results from these are combined in the Figure.

The top surface of each bar in Figure 5-39 corresponds to the mean value of all samples taken in that sampling event. The standard deviation from that mean is also displayed. The data has been further summarized in the table below in Table 5-28.

TABLE 5-28. SUMMARY OF ORGANIC SOLIDS IN MSW

DATE	AVERAGE	STD. DEVIATION
FLB 5.1 (two sub-cells A and B)		
2000/2001	43.57	15.81
Oct 2002	33.06	10.43
%Difference between sampling events = 24% decrease		
FLB 5.2 (two sub-cells A and B)		
2000/2001	36.38	12.75
Oct 2002	32.90	10.40
Difference between sampling events = 10% decrease		
Control 7.3A		
2000/2001	67.19	16.35
Oct 2002	41.67	11.61
Difference between sampling events = 38% decrease		
Control 7.3B		
2000/2001	63.54	16.84
Oct 2002	45.96	15.82
Difference between sampling events = 28% decrease		
AALB 7.4A		
2000/2001	62.46	12.07
Oct 2002	41.94	5.96

DATE	AVERAGE	STD. DEVIATION
Difference between sampling events = 33% decrease		
AALB 7.4B		
2000/2001	82.55	4.19
Oct 2002	37.78	8.84
Difference between sampling events = 55% decrease		

In all cells, values for percent volatile solids show a decrease between 2000/2001 and October 2002.

Summary of Biochemical Methane Production (BMP) in MSW

A summary Biochemical Methane Production (BMP) is displayed graphically in Figure 5-40. The Figure is expressed in a similar form to Figure 5-39, and the interpretation of this representation provided above for volatile solids is also applicable to this. It represents the same two sampling events and is an average of the same samples.

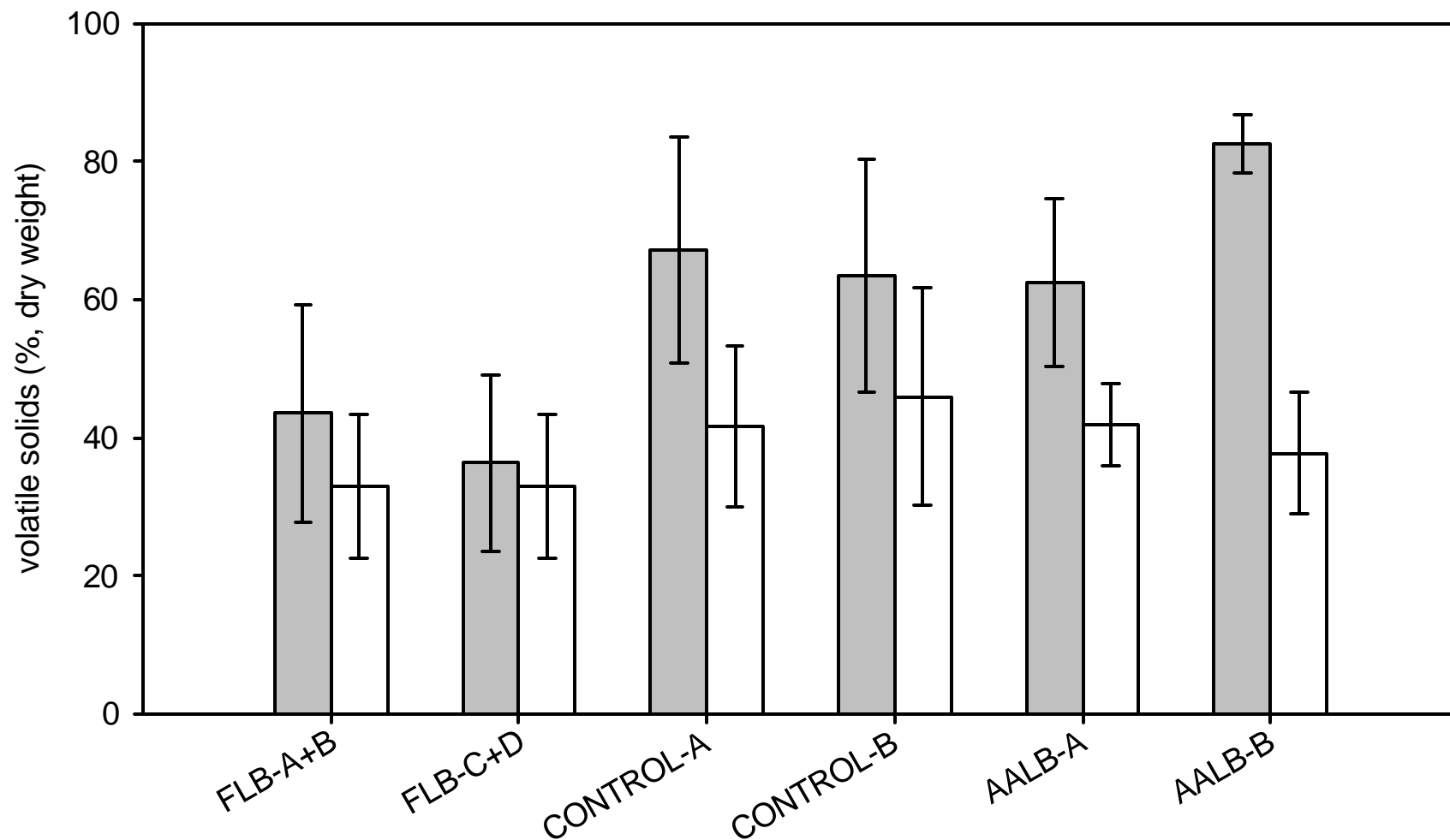
The data have been further summarized below in Table 5-29.

TABLE 5-29. SUMMARY OF BMP IN MSW

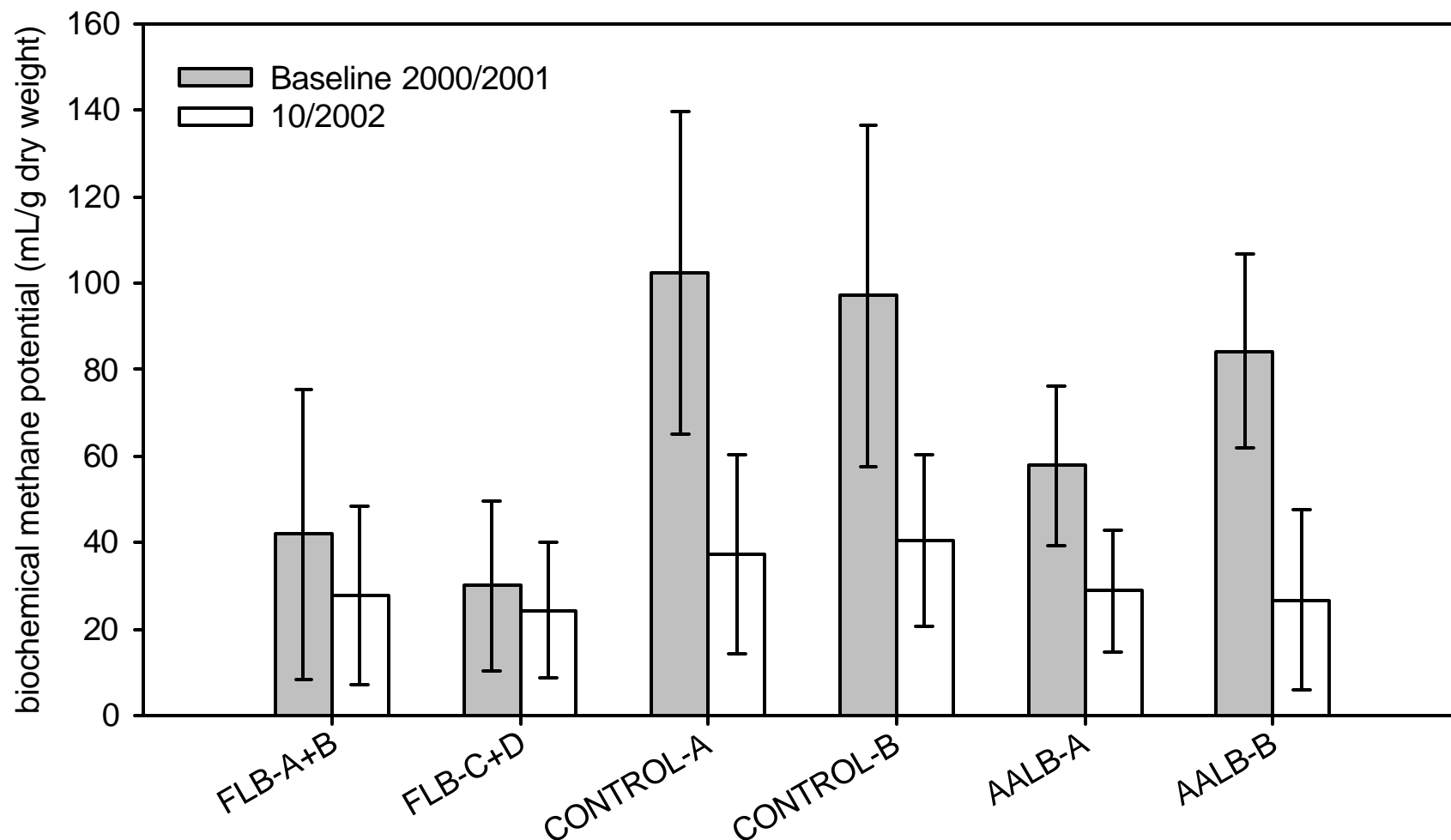
DATE	AVERAGE	STD. DEVIATION
FLB 5.1 (two sub-cells A and B)		
2000/2001	41.81	33.49
Oct 2002	27.64	20.57
%Difference between sampling events = 34% decrease*		
FLB 5.2 (two sub-cells A and B)		
2000/2001	29.95	19.66
Oct 2002	24.28	15.77
Difference between sampling events = 19% decrease*		
Control 7.3A		
2000/2001	102.38	37.35
Oct 2002	37.22	22.89
Difference between sampling events = 64% decrease		
Control 7.3B		
2000/2001	97.15	39.53
Oct 2002	40.40	19.73
Difference between sampling events = 58% decrease		
AALB 7.4A		
2000/2001	57.68	18.49
Oct 2002	28.77	14.17
Difference between sampling events = 50% decrease		
AALB 7.4B		
2000/2001	84.22	22.32
Oct 2002	26.70	20.70
Difference between sampling events = 68% decrease		

Overall, the BMP shows a decrease between 2000/2001 and October 2002 in all cells. *The smallest decrease is seen in the FLB cells where the standard deviation is significantly greater than the apparent difference, hence therefore no detectable difference can be claimed.

Figure 5-39. Solid Waste Organic Solids Content Summary for FLB, Control and AALB Cells



**Figure 5-40. Solid Waste BMP Summary for
FLB, Control and AALB Cells**



Summary of (Cellulose + Hemicellulose)/Lignin Ratio of MSW

A summary (Cellulose + Hemicellulose)/Lignin Ratio is displayed graphically in Figure 5-41. The Figure is expressed in a similar form to Figure 5-39, and the interpretation of this representation provided above for volatile solids is also applicable to this. It represents the same two sampling events and is an average of the same samples.

The data have been further summarized in the table below In Table 5-30.

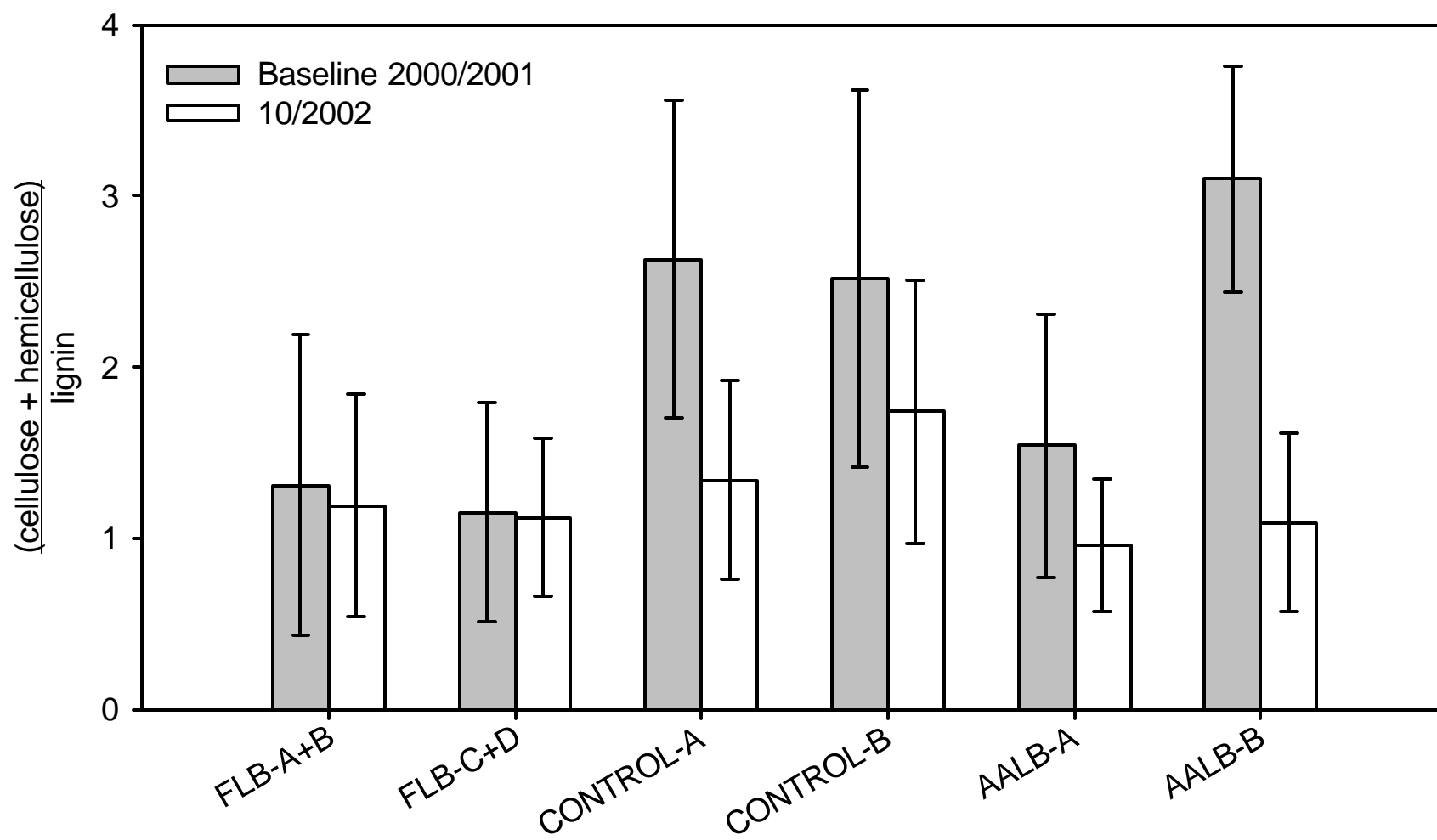
**TABLE 5-30. SUMMARY OF (CELLULOSE + HEMICELLULOSE)/
LIGNIN RATIO OF MSW**

DATE	AVERAGE	STD. DEVIATION
FLB 5.1 (two sub-cells A and B)		
2000/2001	1.31	.088
Oct 2002	1.19	0.65
%Difference between sampling events = 9% decrease		
FLB 5.2 (two sub-cells A and B)		
2000/2001	1.15	0.64
Oct 2002	1.12	0.46
Difference between sampling events = 3% decrease		
Control 7.3A		
2000/2001	2.36	0.93
Oct 2002	1.34	0.58
Difference between sampling events = 43% decrease		
Control 7.3B		
2000/2001	2.52	1.10
Oct 2002	1.74	0.77
Difference between sampling events = 31% decrease		
AALB 7.4A		
2000/2001	1.54	0.77
Oct 2002	0.96	0.39
Difference between sampling events = 38% decrease		
AALB 7.4B		
2000/2001	3.10	0.66
Oct 2002	1.09	0.52
Difference between sampling events = 65% decrease		

Overall, a decrease in the (Cellulose + Hemicellulose)/Lignin ratio is seen in the Control and AALB cells. The FLB values have remained essentially constant between 2000/2001 and October 2002, with the standard deviation in the measurements significantly outweighing any apparent change.

This ratio is affected by the rate of decay of the hemicellulose and cellulose versus that of lignin. These plant polymers make up a large percentage of the biodegradable fraction of landfill waste and hence provide indicators of the waste degradation. Cellulose and hemicellulose are readily biodegradable in the landfill environment, whereas lignin has a much slower rate of decay. Monitoring of this ratio can provide a measure of waste degradation independent of the quantity of different materials present in the landfill, allowing comparisons over time and across samples.

Figure 5-41. Solid Waste (Cellulose + Hemicellulose)/Lignin Ratio Summary for FLB, Control and AALB Cells



Summary of Lignin Content of MSW

A summary of lignin content is displayed graphically in Figure 5-42. The Figure is expressed in a similar form to Figure 5-39, and the interpretation of this representation provided above for volatile solids is also applicable to this. It represents the same two sampling events and is an average of the same samples.

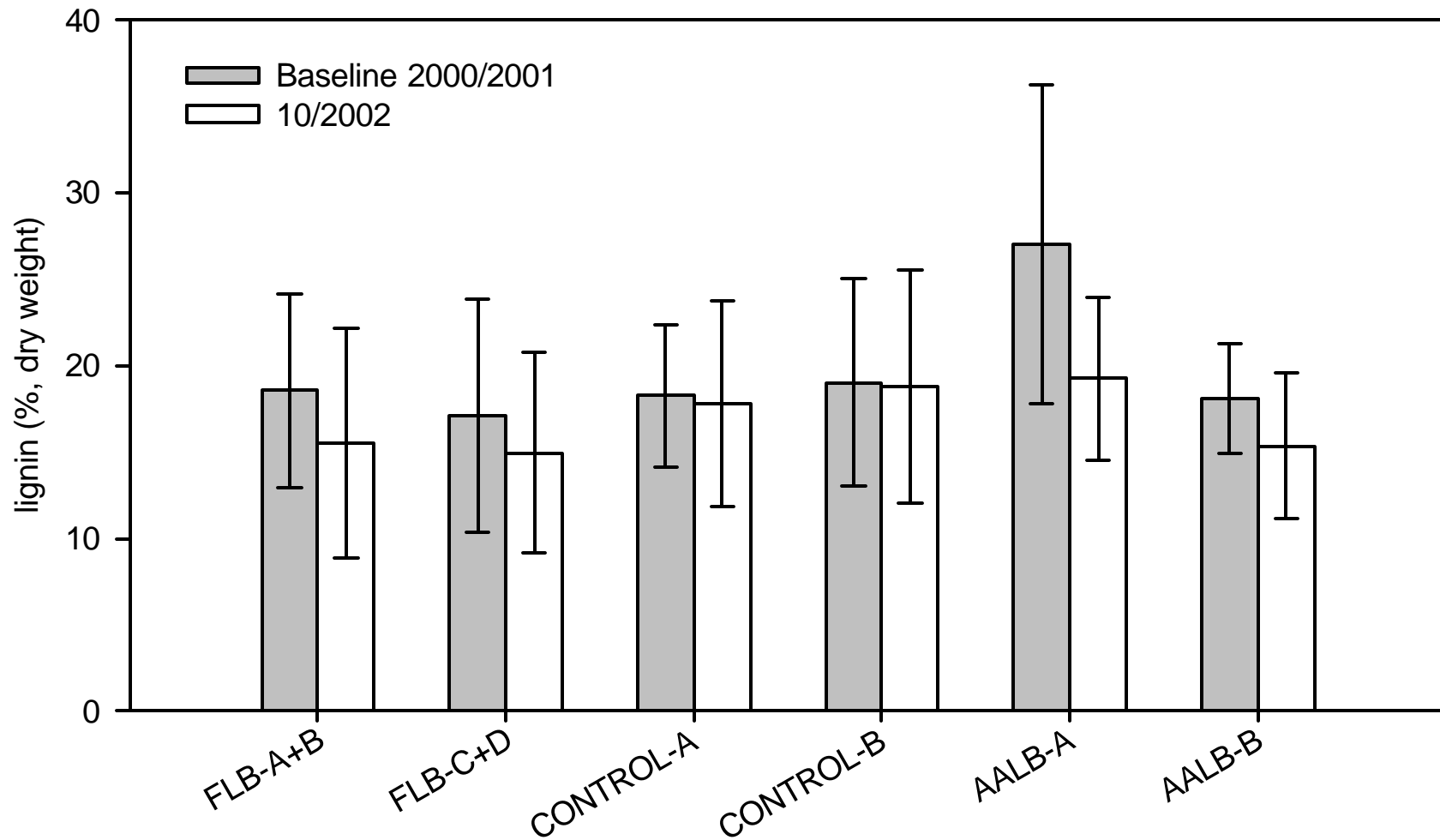
The data have been further summarized below in Table 5-31.

TABLE 5-31. SUMMARY OF LIGNIN CONTENT OF MSW

DATE	AVERAGE	STD. DEVIATION
FLB 5.1 (two sub-cells A and B)		
2000/2001	18.56	5.64
Oct 2002	15.50	6.65
%Difference between sampling events = 16% decrease		
FLB 5.2 (two sub-cells B and C)		
2000/2001	17.11	6.79
Oct 2002	14.95	5.80
Difference between sampling events = 13% decrease		
Control 7.3A		
2000/2001	18.24	4.08
Oct 2002	17.83	5.94
Difference between sampling events = 2% decrease		
Control 7.3B		
2000/2001	19.01	5.99
Oct 2002	18.79	6.72
Difference between sampling events = 1% decrease		
AALB 7.4A		
2000/2001	27.00	9.23
Oct 2002	19.24	4.69
Difference between sampling events = 29% decrease		
AALB 7.4B		
2000/2001	18.12	3.15
Oct 2002	15.35	4.21
Difference between sampling events = 15% decrease		

Overall, a decrease is seen in the lignin content in the treated cells FLB and AALB, while the lignin content in the control cells has remained constant over the period. However, in all cases the standard deviation is significantly greater than the observed differences.

Figure 5-42. Solid Waste Lignin Content Summary for FLB, Control and AALB Cells



Summary of Hemicellulose Content of MSW

A summary of the hemicellulose content is displayed graphically in Figure 5-43. The Figure is expressed in a similar form to Figure 5-39, and the interpretation of this representation provided above for volatile solids is also applicable to this. It represents the same two sampling events and is an average of the same samples.

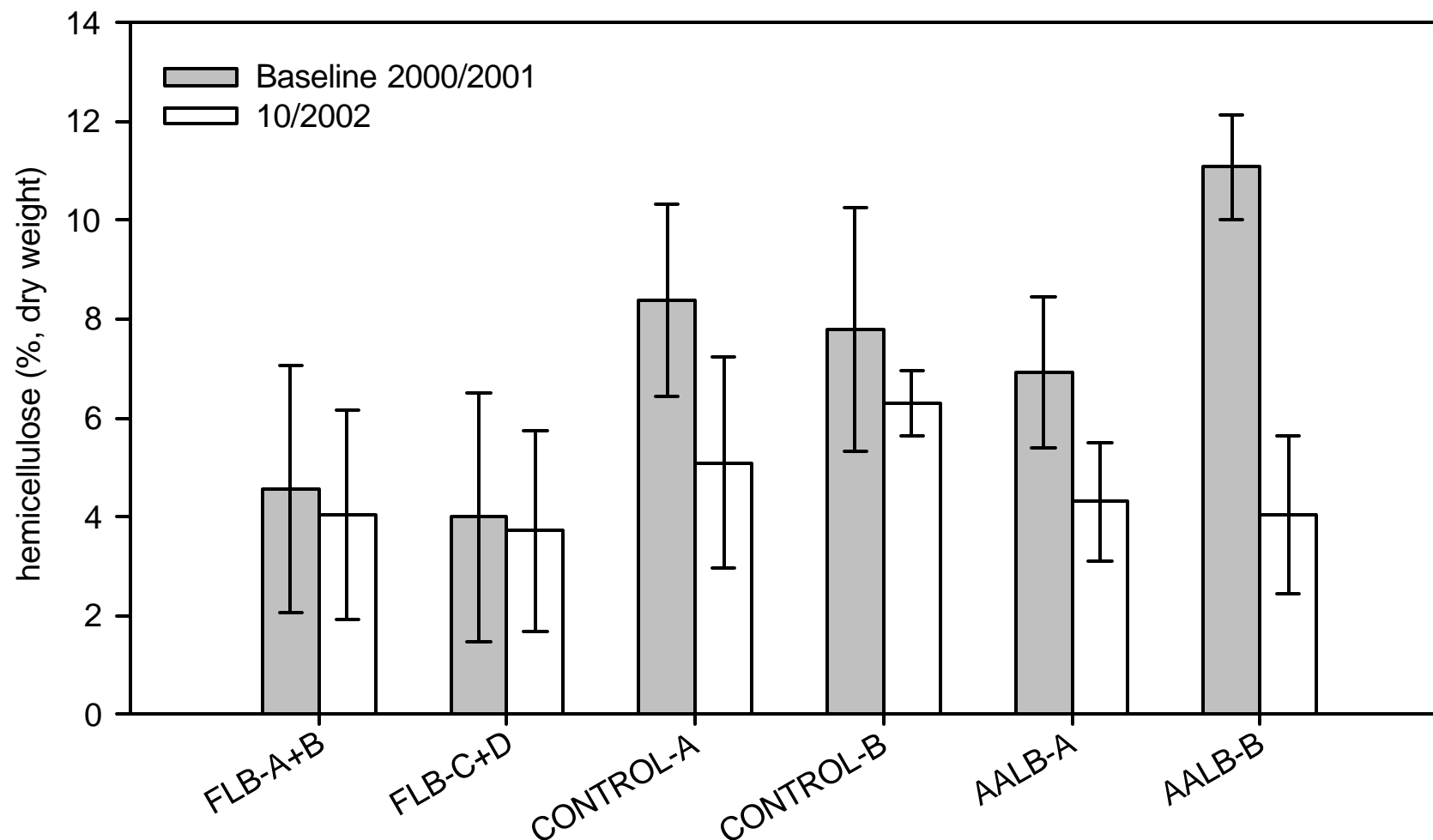
The data have been further summarized below in Table 5-32.

TABLE 5-32. SUMMARY OF HEMICELLULOSE IN MSW

DATE	AVERAGE	STD. DEVIATION
FLB 5.1 (two sub-cells A and B)		
2000/2001	4.56	2.51
Oct 2002	4.04	2.13
%Difference between sampling events = 11% decrease		
FLB 5.2 (two sub-cells A and B)		
2000/2001	4.00	2.52
Oct 2002	3.72	2.03
Difference between sampling events = 7% decrease		
Control 7.3A		
2000/2001	8.38	1.96
Oct 2002	5.10	2.15
Difference between sampling events = 39% decrease		
Control 7.3B		
2000/2001	7.80	2.47
Oct 2002	6.28	0.66
Difference between sampling events = 19% decrease		
AALB 7.4A		
2000/2001	6.92	1.52
Oct 2002	4.31	1.20
Difference between sampling events = 38% decrease		
AALB 7.4B		
2000/2001	11.09	1.06
Oct 2002	4.03	1.60
Difference between sampling events = 64% decrease		

Overall, a decrease in the hemicellulose content is seen for all cells over the period. The largest decrease is seen in the AALB B cell. The smallest decrease is seen in the FLB cells, where the standard deviation is significantly greater than the observed difference.

Figure 5-43. Solid Waste Hemicellulose Content Summary for FLB, Control and AALB Cells



Summary of Cellulose Content of MSW

A summary of cellulose content is displayed graphically in Figure 5-44. The Figure is expressed in a similar form to Figure 5-39, and the interpretation of this representation provided above for volatile solids is also applicable to this. It represents the same two sampling events and is an average of the same samples.

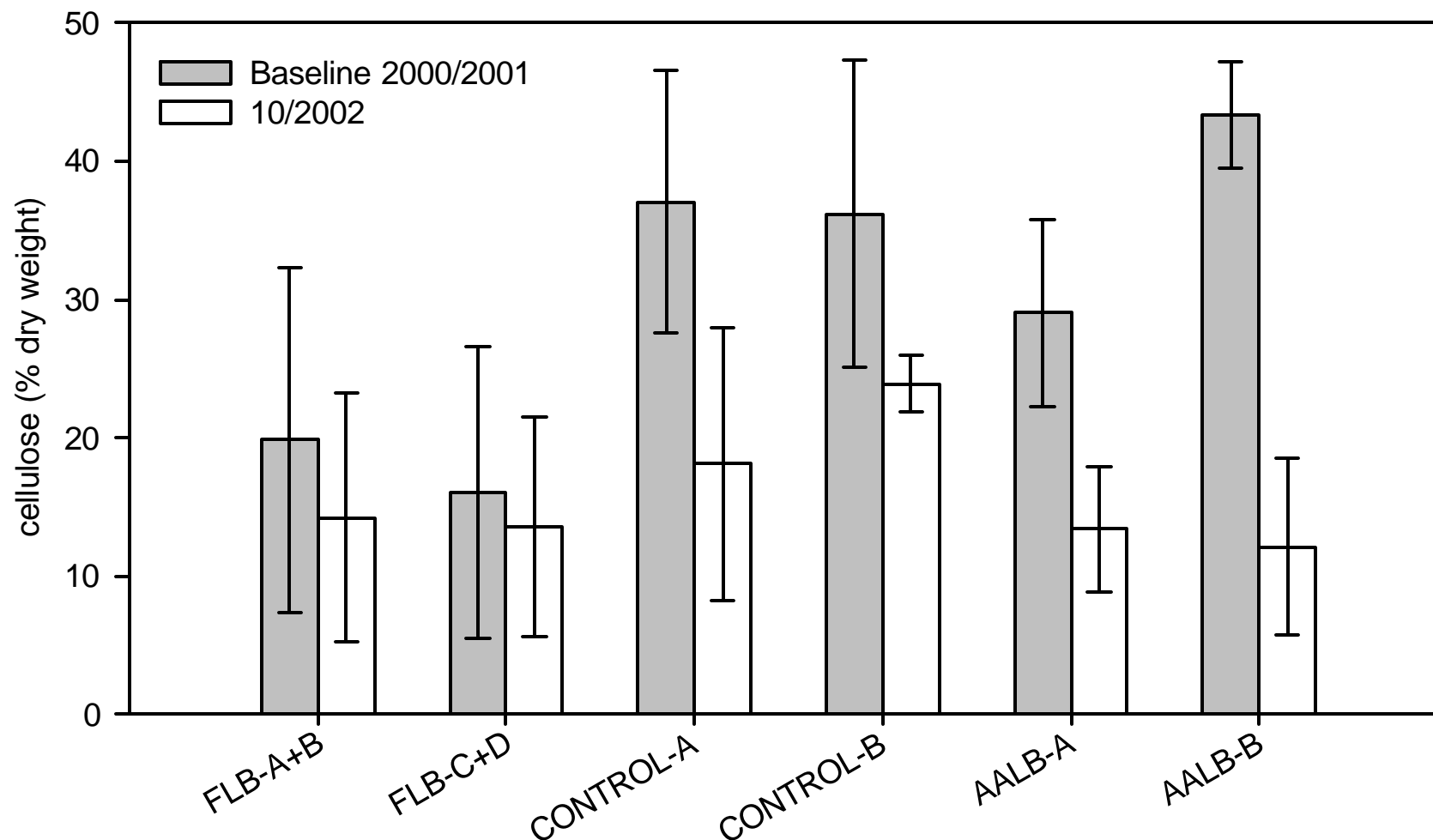
The data have been further summarized below in Table 5-33.

TABLE 5-33. SUMMARY OF CELLULOSE CONTENT OF MSW

DATE	AVERAGE	STD. DEVIATION
FLB 5.1 (two sub-cells A and B)		
2000/2001	19.84	12.48
Oct 2002	14.20	9.00
%Difference between sampling events = 28% decrease		
FLB 5.2 (two sub-cells A and B)		
2000/2001	16.02	10.52
Oct 2002	13.53	7.93
Difference between sampling events = 16% decrease		
Control 7.3A		
2000/2001	37.06	9.51
Oct 2002	18.13	9.89
Difference between sampling events = 51% decrease		
Control 7.3B		
2000/2001	36.18	11.09
Oct 2002	23.91	2.08
Difference between sampling events = 34% decrease		
AALB 7.4A		
2000/2001	29.03	6.74
Oct 2002	13.40	4.56
Difference between sampling events = 54% decrease		
AALB 7.4B		
2000/2001	43.28	3.85
Oct 2002	12.14	6.34
Difference between sampling events = 72% decrease		

Overall, a decrease in the cellulose content is seen in all cells over the period. The standard deviation associated with the FLB data is significantly greater than the difference observed. The largest decrease was seen in the AALB B cell.

Figure 5-44. Solid Waste Cellulose Content Summary for FLB, Control and AALB Cells



Summary of Moisture Content of MSW

A summary of the moisture content is displayed graphically in Figure 5-45. The Figure is expressed in a similar form to Figure 5-39, and the interpretation of this representation provided above for volatile solids is also applicable to this. It represents the same two sampling events and is an average of the same samples.

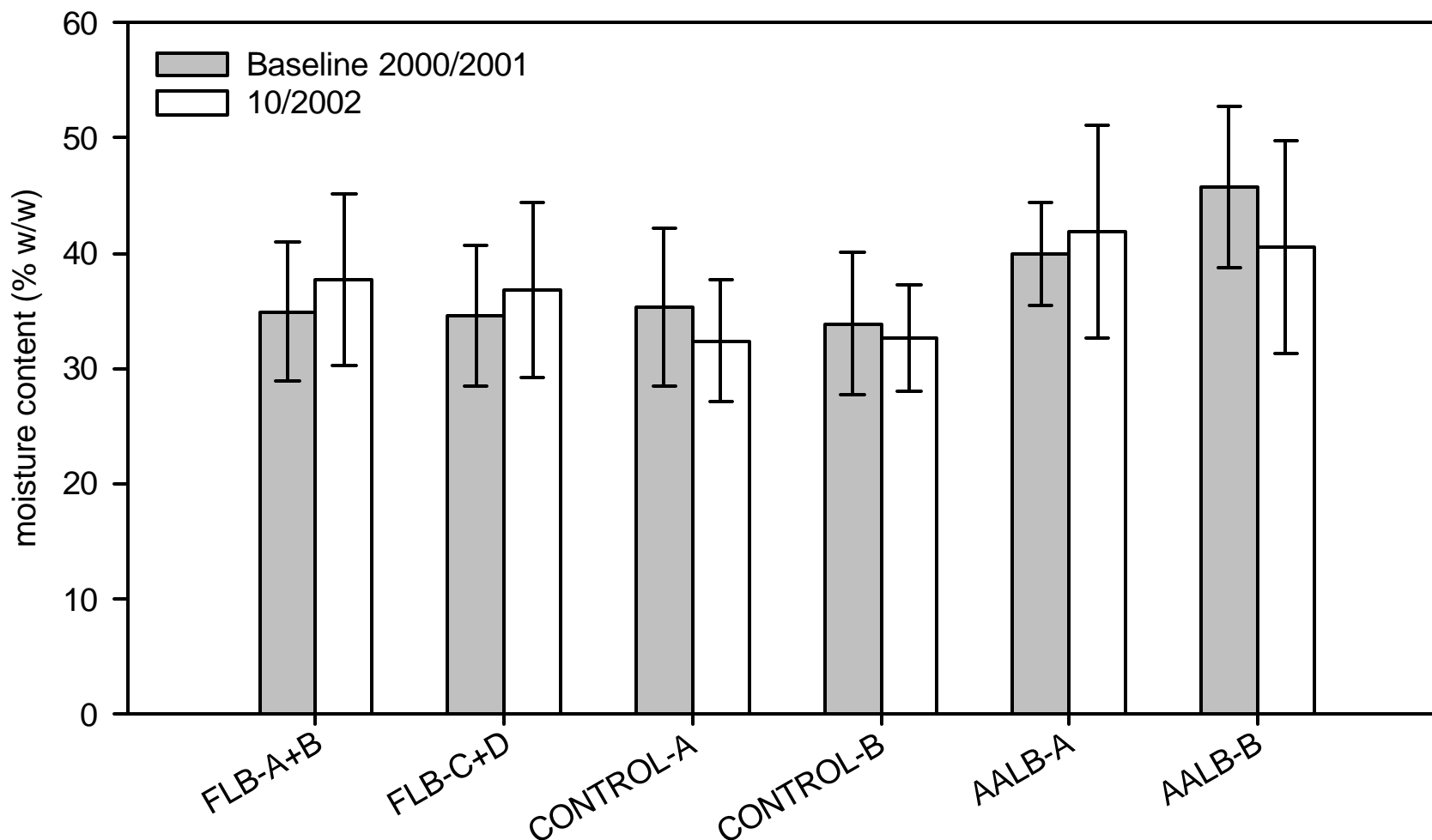
The data have been further summarized below in Table 5-34.

TABLE 5-34. SUMMARY OF MOISTURE CONTENT OF MSW

DATE	AVERAGE	STD. DEVIATION
FLB 5.1 (two sub-cells A and B)		
2000/2001	34.95	6.01
Oct 2002	37.69	7.47
%Difference between sampling events = 8% increase		
FLB 5.2 (two sub-cells A and B)		
2000/2001	34.52	6.12
Oct 2002	36.81	7.64
Difference between sampling events = 7% increase		
Control 7.3A		
2000/2001	35.34	6.81
Oct 2002	32.39	5.27
Difference between sampling events = 8% decrease		
Control 7.3B		
2000/2001	33.90	6.15
Oct 2002	32.63	4.57
Difference between sampling events = 4% decrease		
AALB 7.4A		
2000/2001	39.97	4.46
Oct 2002	41.91	9.19
Difference between sampling events = 5% increase		
AALB 7.4B		
2000/2001	45.78	7.01
Oct 2002	40.55	9.21
Difference between sampling events = 11% decrease		

Overall, the moisture content of the waste has remained consistent over the period for each cell, and is overall comparable between cells.

Figure 5-45. Solid Waste Moisture Content Summary for FLB, Control and AALB Cells



Summary of Oxidation Reduction Potential (ORP) of MSW

Oxidation-reduction potential (ORP) probes were installed in the waste in the FLB, Control and AALB cells in to assess their usefulness as qualitative indicators of the redox state of the waste during treatment (aerobic or anaerobic). A summary of the mean, maximum and minimum readings for the installed probes in the FLB, Control and AALB cells is provided in the following table.

No clear trends in the ORP measurements over time or in response to various treatments that would be expected to influence the ORP of the waste, such as aeration in the AALB, were observed for these probes. In general the readings are characterized by large fluctuations in ORP spanning a wide range of values.

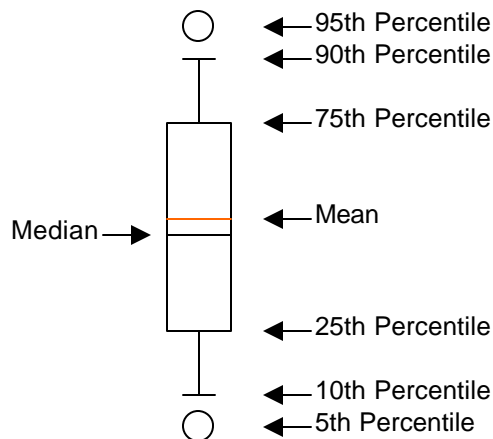
TABLE 5-35. SUMMARY OF ORP DATA FOR FLB, CONTROL AND AALB CELLS

Probe ID	IR Nomenclature	Mean (mV)	Maximum (mV)	Minimum (mV)
51A O01	FLB-A No.1	21.5929	203.0000	-88.0000
51A O02	FLB-A No.2	-336.4054	168.0000	-511.0000
51A O03	FLB-A No.3	183.2729	546.0000	-159.0000
51A O04	FLB-A No.4	285.4352	363.0000	0.0000
51B O01	FLB-B No.1	346.7713	564.0000	-270.0000
52A O01	FLB-C No. 1	10.4687	634.0000	0.0000
52B O01	FLB-D No. 1	2.1590	132.0000	0.0000
52B O02	FLB-D No. 2	160.9255	806.0000	-518.0000
52B O03	FLB-D No. 3	-36.0699	115.0000	-640.0000
52B O04	FLB-D No. 4	85.6895	958.0000	-211.0000
73A O01	Control-A No.1	293.4921	537.0000	-136.0000
73B O01	Control-B No. 1	44.1649	367.0000	-497.0000
74A O01	AALB-A No.1	101.5301	547.0000	-1373.0000
74A O02	AALB-A No.2	-577.4400	261.0000	-1422.0000
74B O01	AALB-B No.1	-135.0144	1049.0000	-526.0000
74B O02	AALB-B No.2	305.9152	1145.0000	0.0000

Summary of Average Temperature of MSW

Temperature readings of the MSW were made on a daily basis via multiple thermocouple probes permanently installed in the waste. These data are captured and graphically represented in the form of box plots for FLB 5.1, FLB 5.2, AALB 7.4A Lifts 1-3, AALB 7.4B Lifts 1-3, and the Control, in Figures 5-46 through 5-54.

Interpretation of the box plot:



Multiple factors affect the recorded temperature within the landfill, including the location of the probe, depth of probe, atmospheric temperature, and volume and temperature of liquids added. Variability between the probes across a given cell is therefore not unexpected as seen in FLB 5.1. FLB 5.2 shows a relatively stable temperature across probes T03 to T14, with a range of ~5-40°C, though averaging ~20°C.

Each lift of the AALB cells shows there to be a relatively good temperature correlation across the lift. This is summarized below in Table 5-36.

TABLE 5-36. SUMMARY OF AVERAGE TEMPERATURE OF MSW

LIFT	APPROX. AVERAGE 10-90TH PERCENTILE TEMPERATURE RANGE (°C)	APPROX. MEAN TEMPERATURE ACROSS PROBES (°C)
AALB 7.4A		
Lift 1	15-45	25
Lift 2	15-45	27
Lift 3	12-23	18
AALB 7.4B		
Lift 1	14-45	28
Lift 2	10-45	28
Lift 3	15-35	25

The Control Unit temperature readings are not divided into the subcells A and B but are combined to represent the entire Control Unit 7.3. It should be noted that several of the thermocouple probes in the Control unit produced erroneous readings. Consequently, the results required a significant degree of censoring. In addition, although the data span the period

March 2002 through April 2003, there were large time gaps for several of the probes that biased the readings. The available data from the probes across the landfill are variable and exhibit large temperature differentials. The average mean temperature for the site can be estimated as approximately 17°C.

LANDFILL GAS (LFG) CHARACTERISTICS

Landfill gas parameters were measured both on-site using a GEM 200 field instrument on a weekly basis, and by sample collection in a 6-liter SUMMA[®] canister for off-site lab analysis on a quarterly basis. The results documented in this report apply only to the Control Unit (7.3 A and B) and the FLB (Unit 5.1 and 5.2) as these units contain waste of sufficient age to be generating LFG (methanogenesis phase).

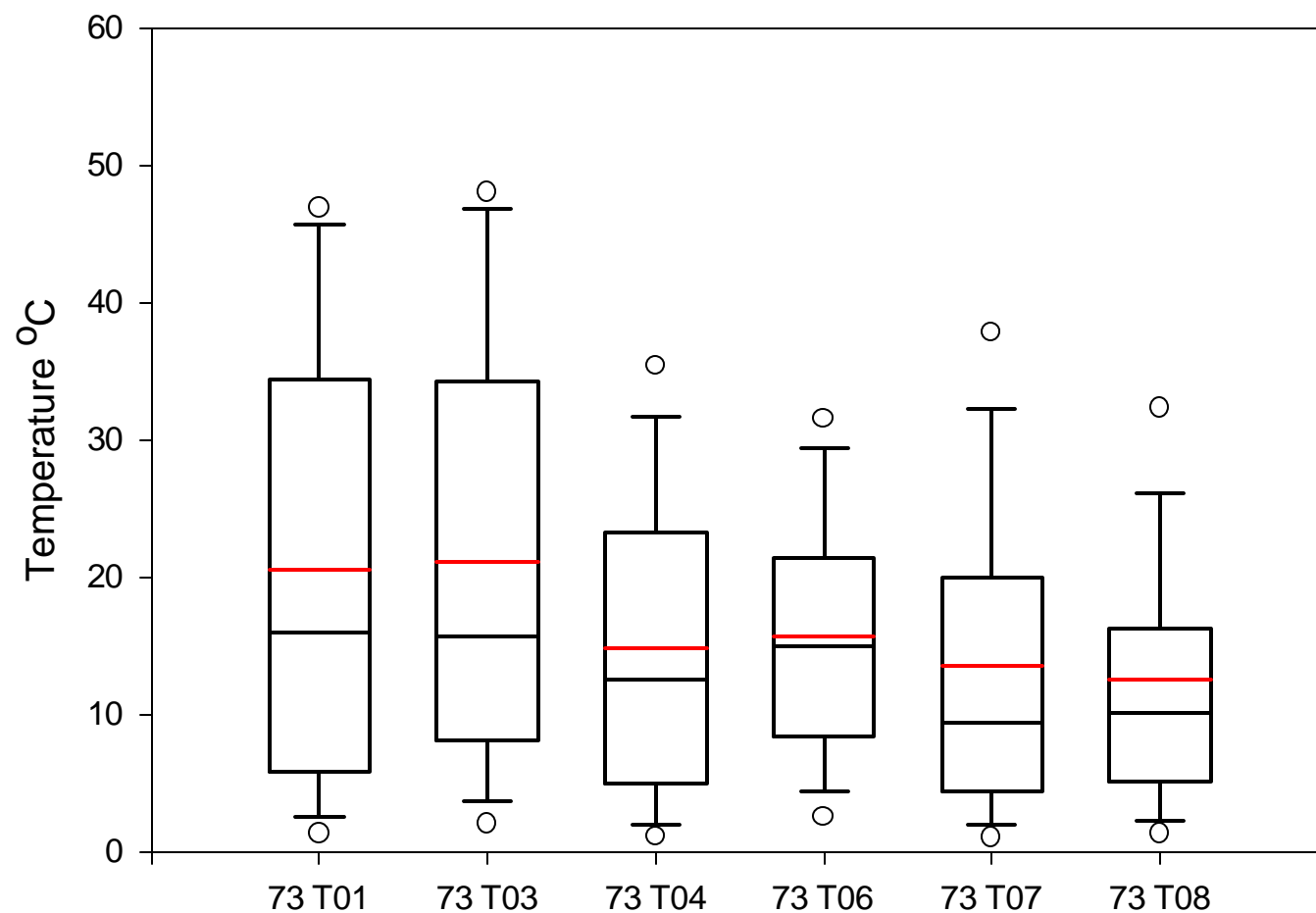
Summary of Landfill Gas Flow

The collected landfill gas flow rate was measured for both Control cells 7.3 A and B and the FLB cells 5.1 and 5.2. The rate of flow was measured weekly using a calibrated orifice plate at the installed gas monitoring wells within each cell. Control cells 7.3 A and B both have two monitoring wells (referred to as 1 and 2), while each of the FLB cells, 5.1 and 5.2, has one. The results are graphically displayed in Figures 5-55 and 5-56.

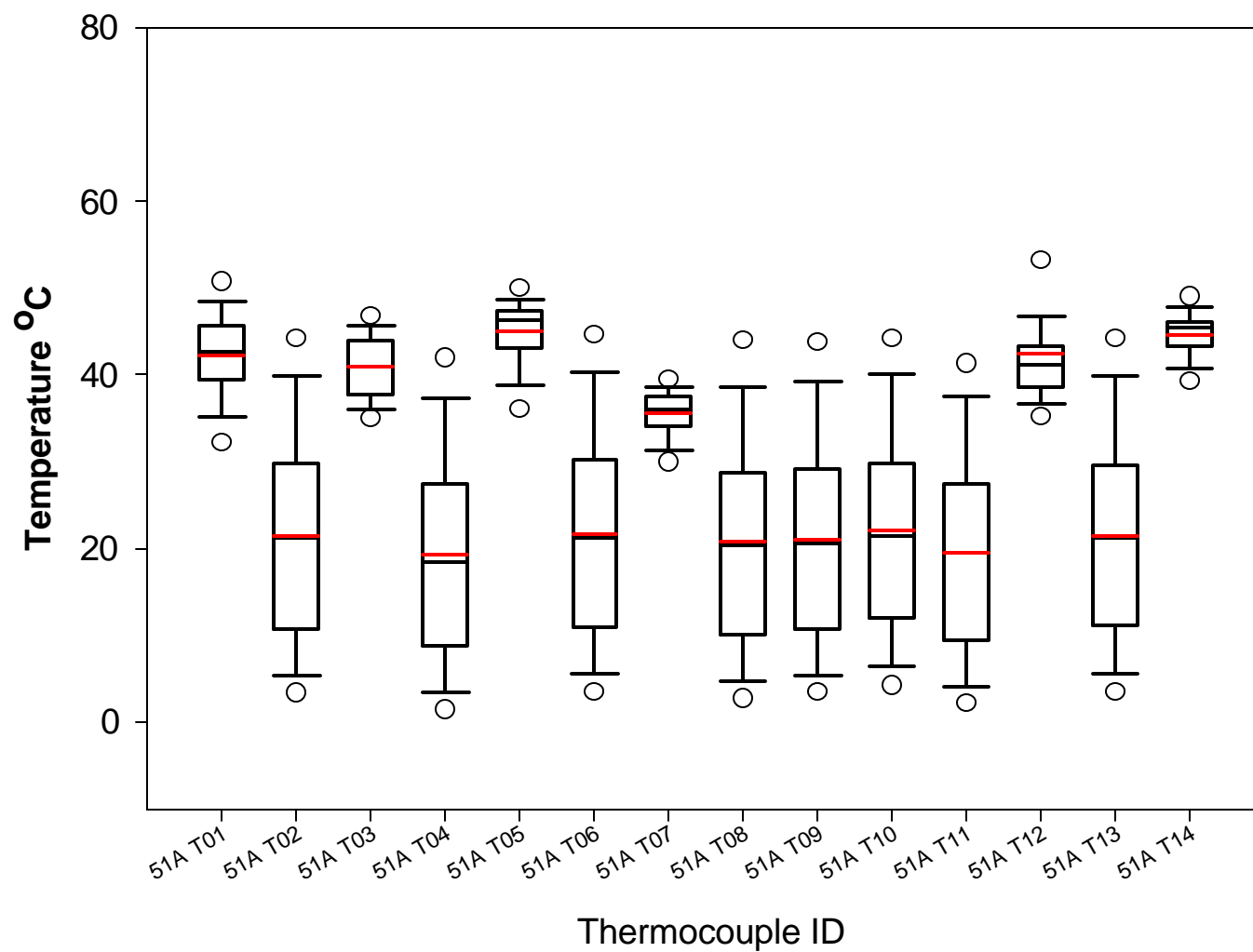
The results available for this report span approximately 16 months from January 2002 until May 2003. Landfill gas flow rate has remained steady throughout this period in both Control cells, as shown by the relatively level plots at each of the four monitoring points. In Control cell A, the mean value measured was in the range 47 to 49 scfm at well 1, and 29 to 31 scfm at well 2. In Control cell B, the mean value measured was in the range 45 to 47 scfm at well 1, and 32 to 34 scfm at well 2.

The results for the FLB, over approximately the same period, show a flow of between approximately 300 to 500 scfm in both cells until approximately June 2002 when a significant drop in the flow rate occurred. This steady drop occurred between approximately May and July for FLB 5.1, and between July and September 2002 in FLB 5.2. The production rate then remained relatively constant in a range of 50 to 250 scfm in both cells until May 2003.

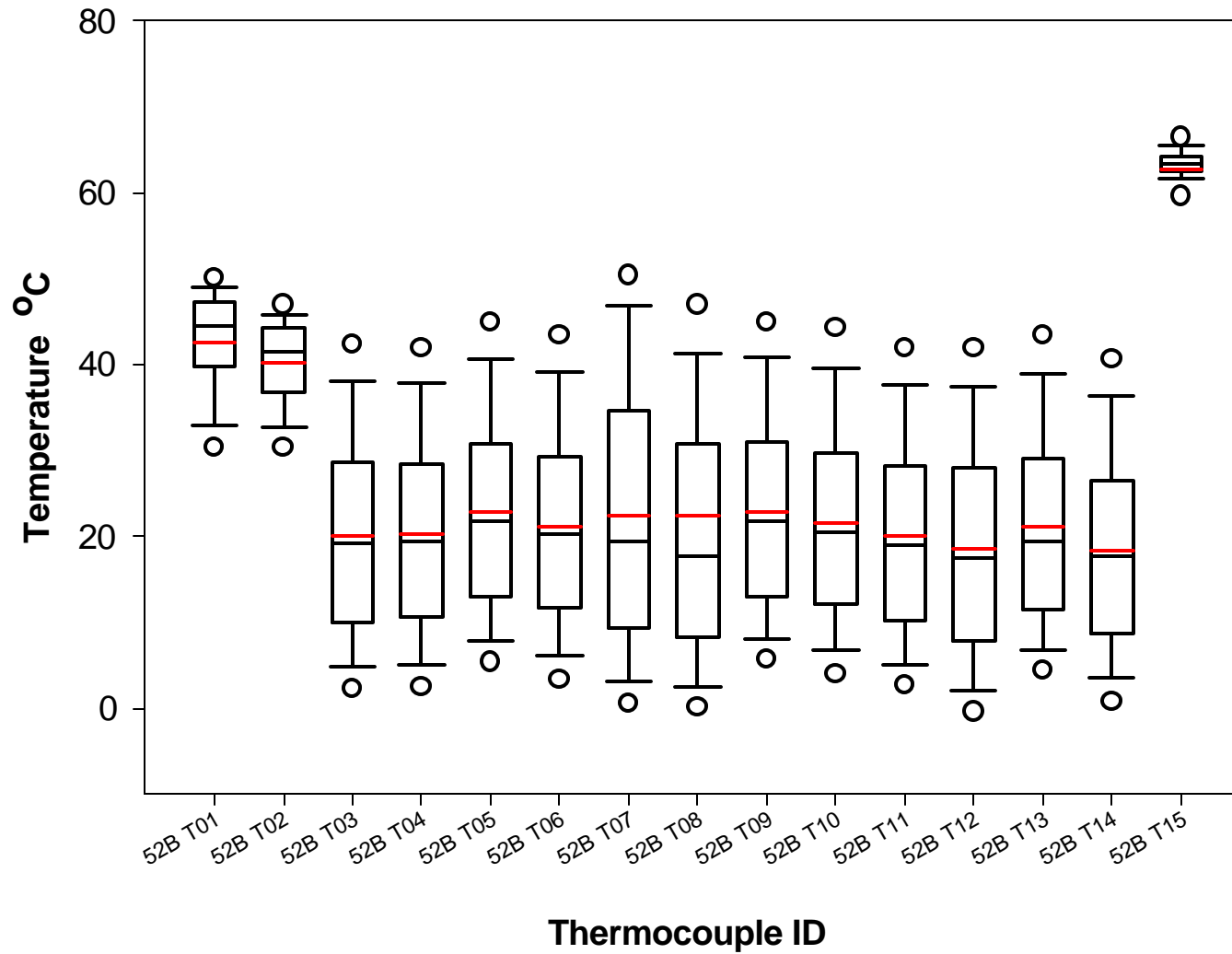
**Figure 5-46. Box Plot of Control Cell Waste Thermocouple Readings
(3/2002 - 4/2003)**



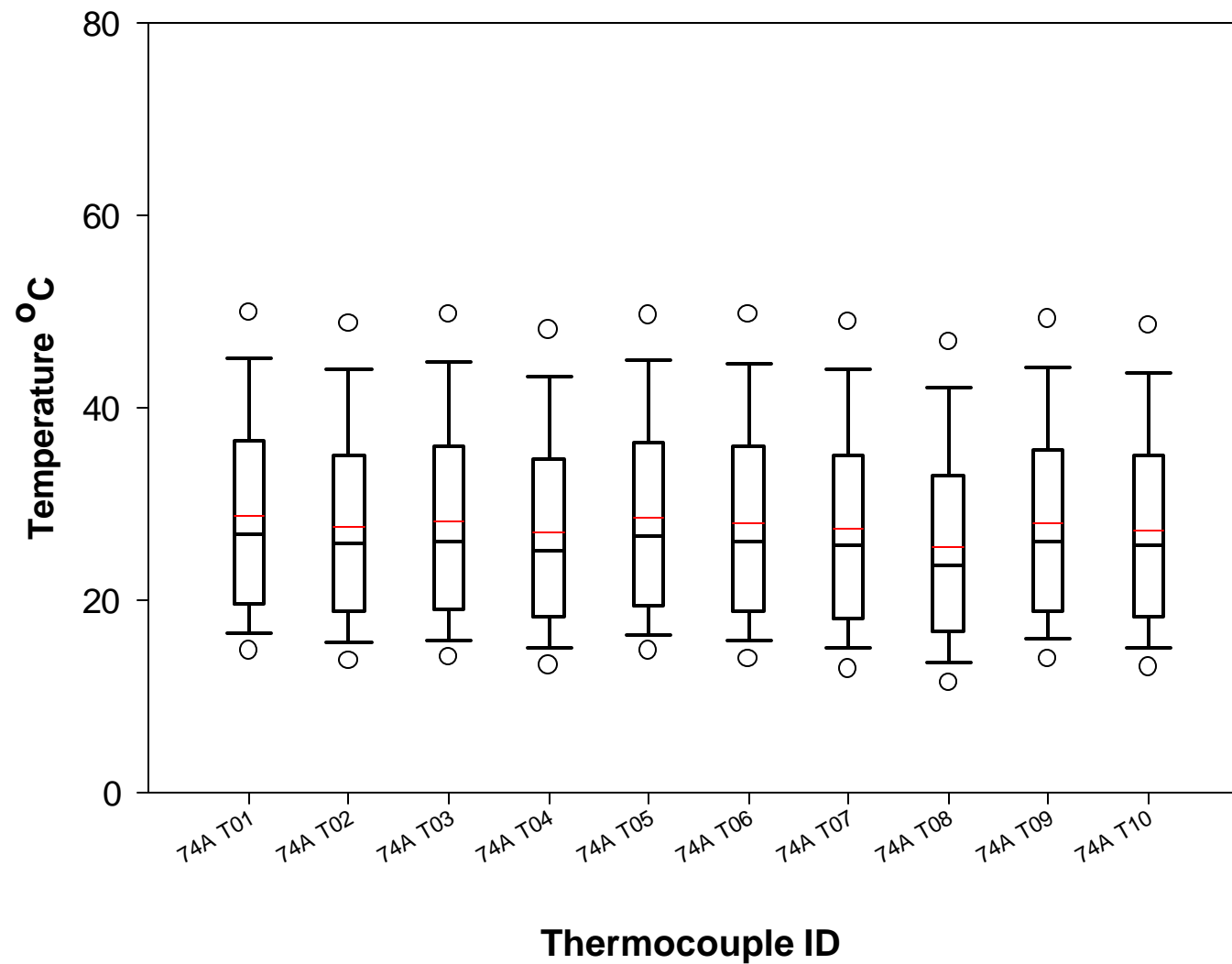
**Figure 5-47. FLB (5.1A) Waste Thermocouple Readings
(3/12/2002 - 4/1/2003)**



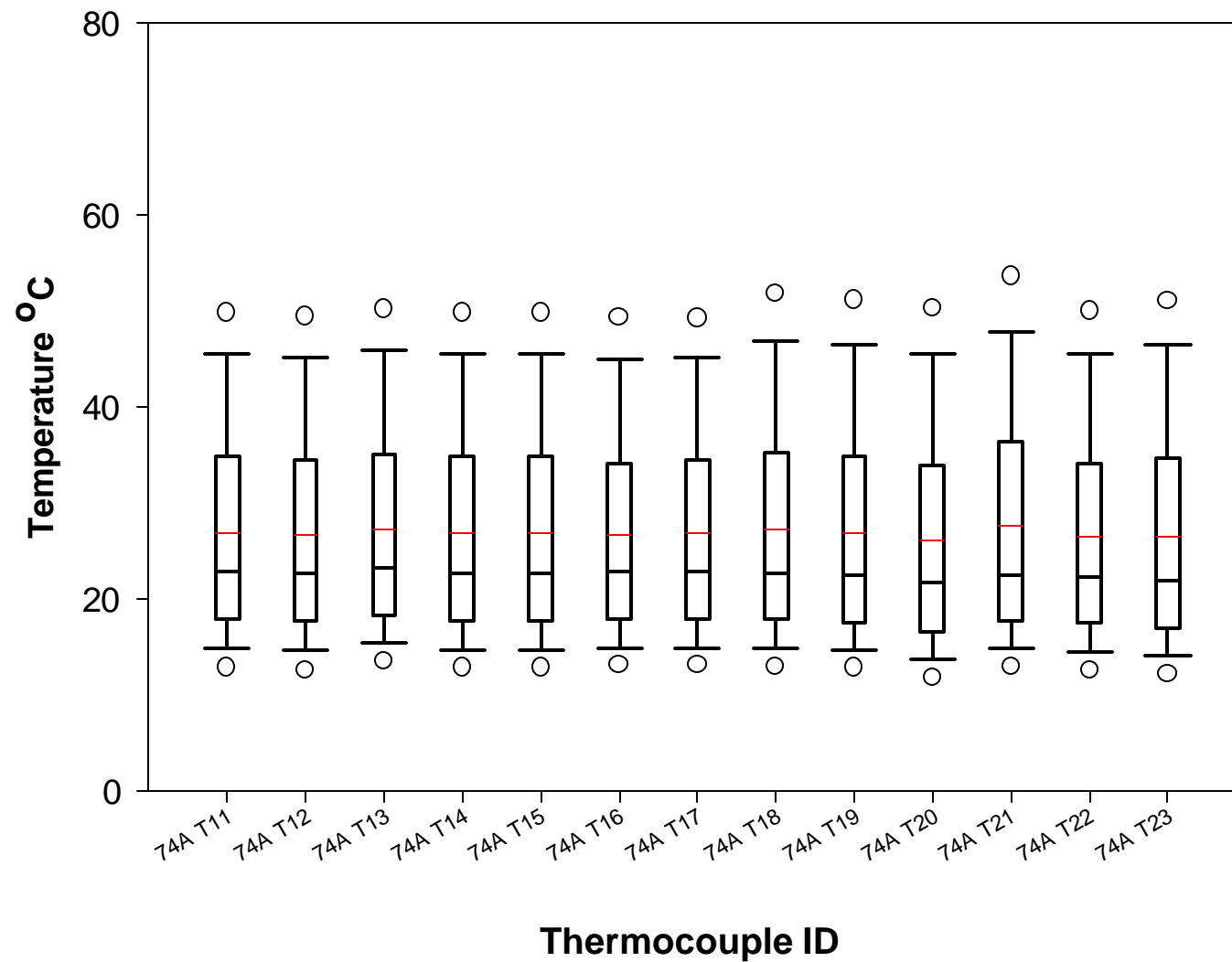
**Figure 5-48. FLB (5.2D) Waste Thermocouple Readings
(3/12/2002 - 4/1/2003)**



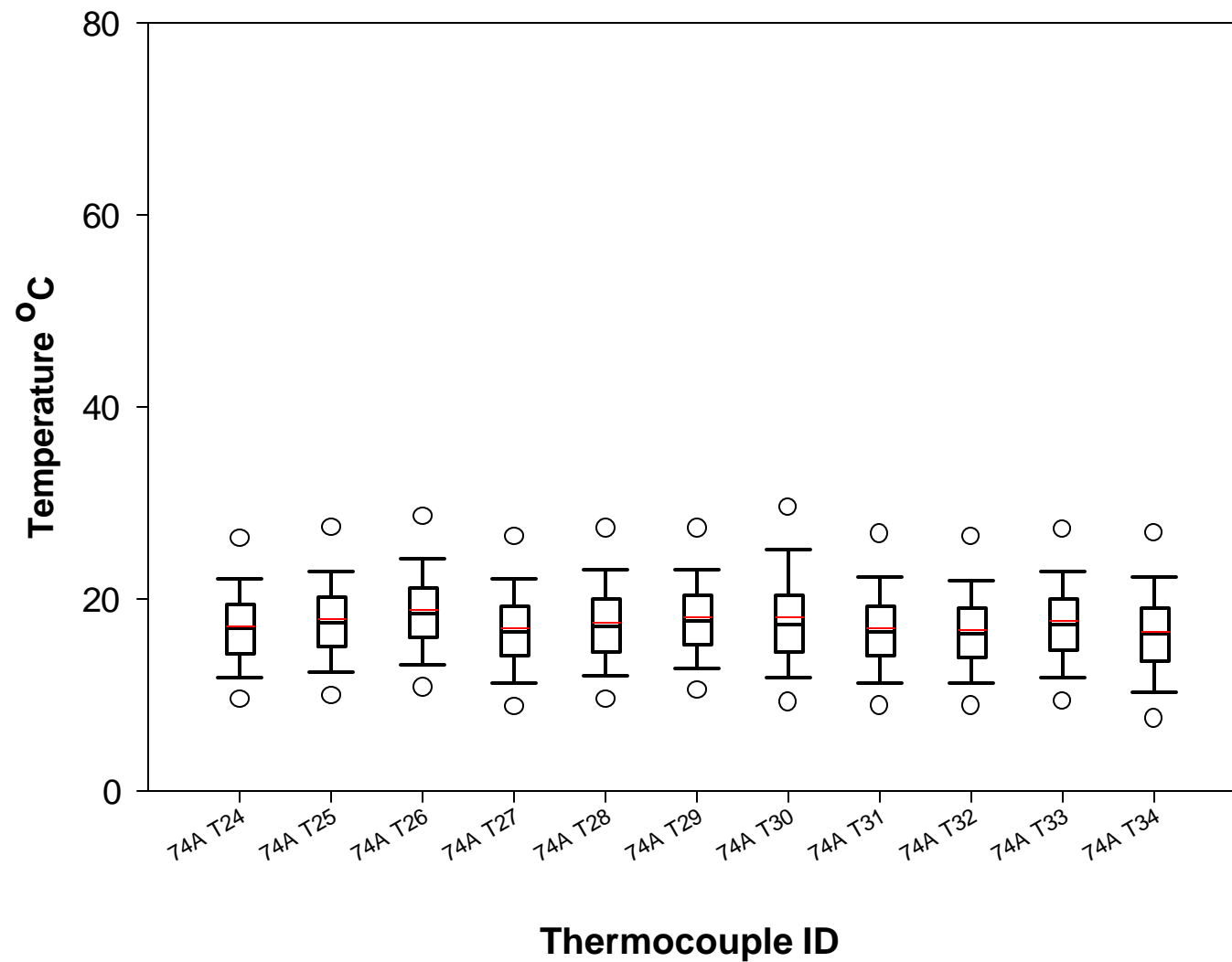
**Figure 5-49. AALB (7.4A) Lift 1 Waste Thermocouple Readings
(3/13/2002 - 4/1/2003)**



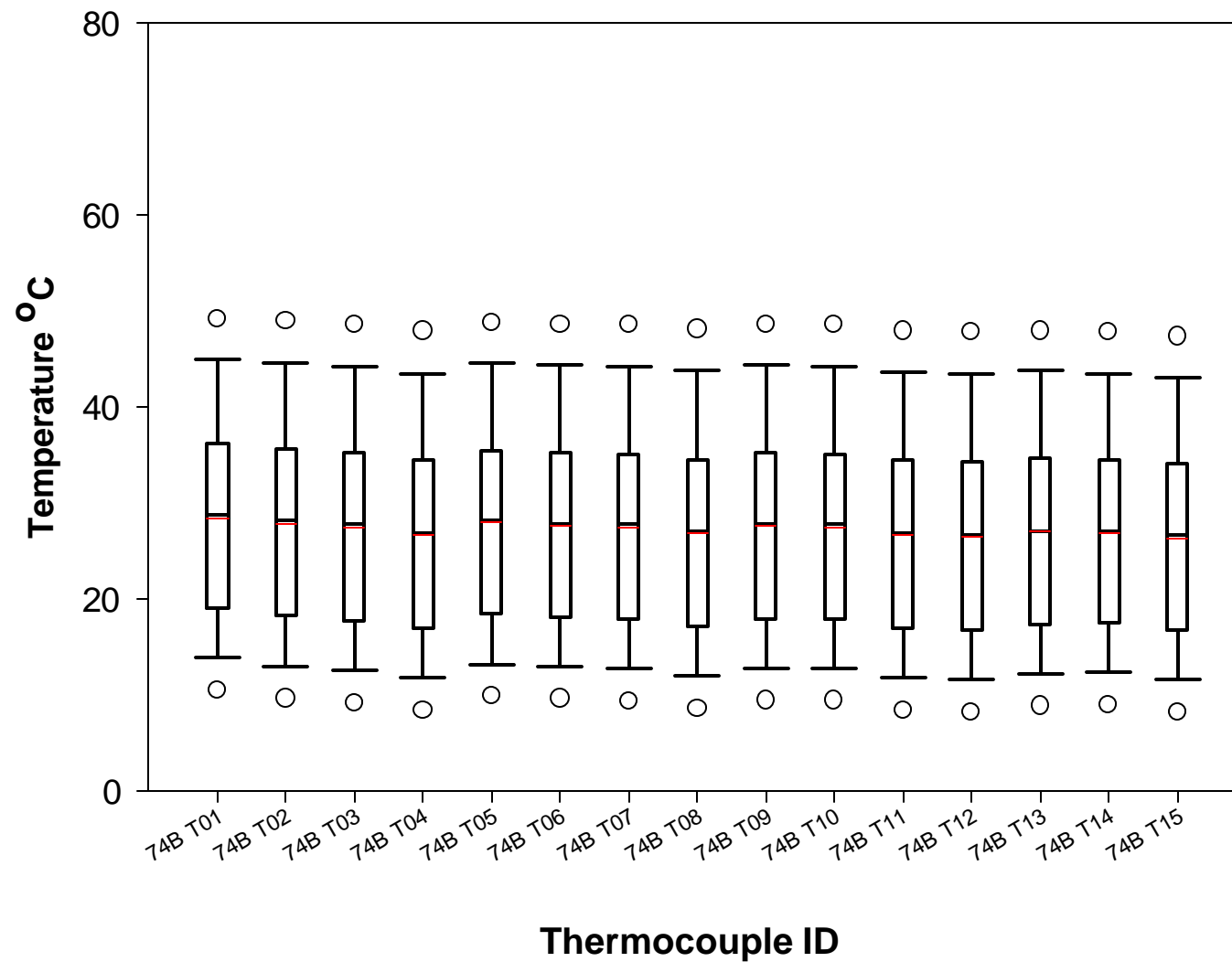
**Figure 5-50. AALB (7.4A) Lift 2 Waste Thermocouple Readings
(5/29/2002 - 4/1/2003)**



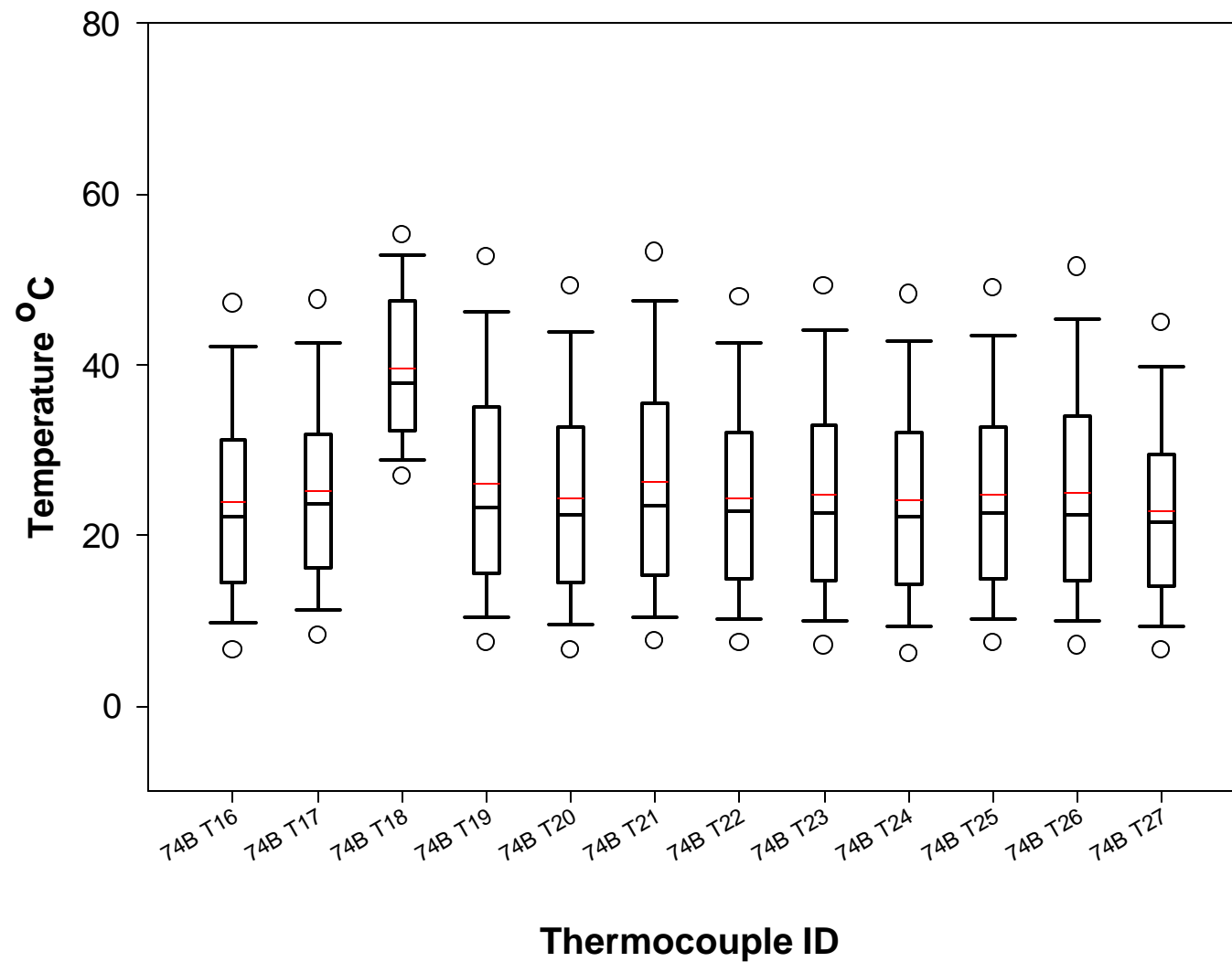
**Figure 5-51. AALB (7.4A) Lift 3 Waste Thermocouple Readings
(11/4/2002 - 4/1/2003)**



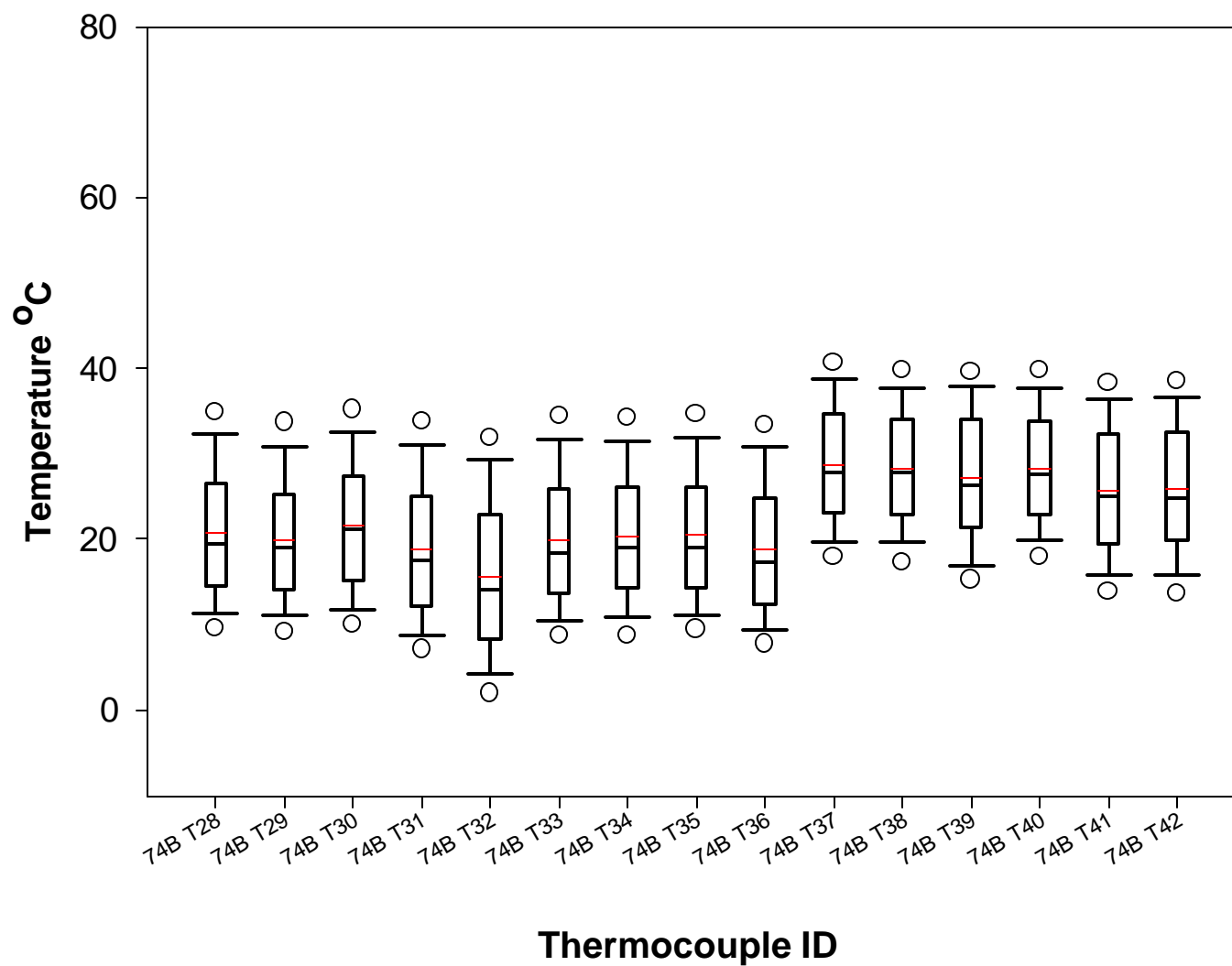
**Figure 5-52. AALB (7.4B) Lift 1 Waste Thermocouple Readings
(3/13/2002 - 4/1/2003)**



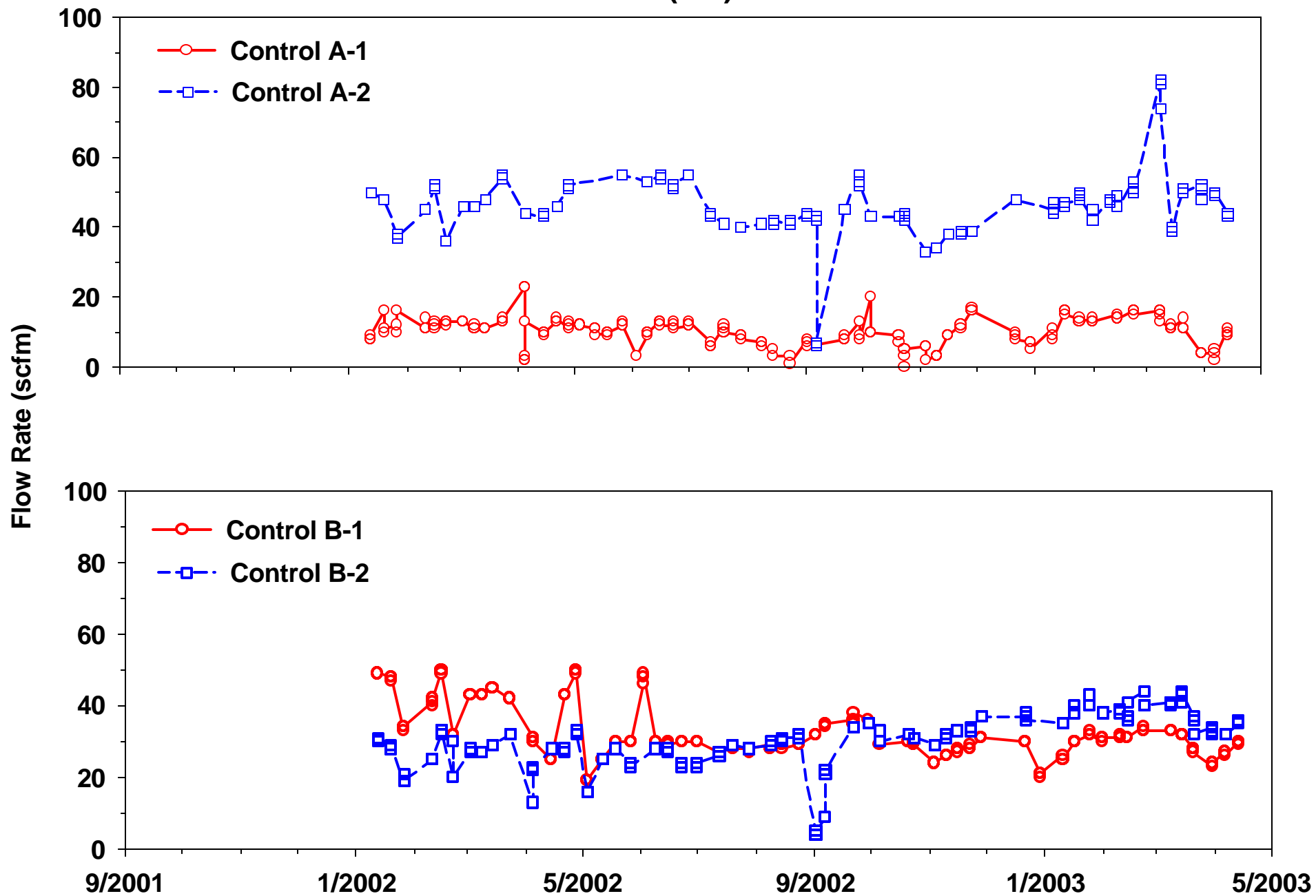
**Figure 5-53. AALB (7.4B) Lift 2 Waste Thermocouple Readings
(7/1/2002 - 4/1/2003)**



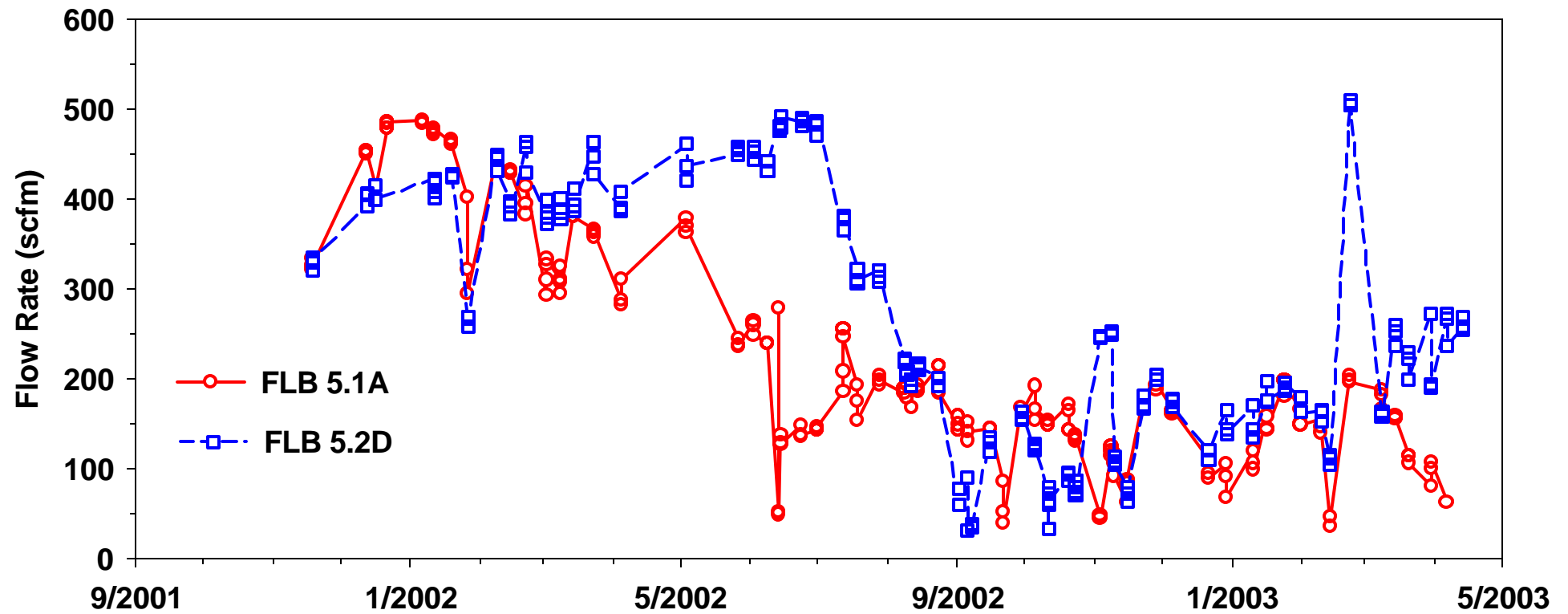
**Figure 5-54. AALB (7.4B) Lift 3 Waste Thermocouple Readings
(2/3/2003 - 4/1/2003)**



**Figure 5-55. Landfill Gas Flow vs. Time for
Control (7.3) A and B**



**Figure 5-56. Landfill Gas Flow vs. Time for
FLB 5.1A and 5.2D**



Summary of Landfill Gas Temperature

The landfill gas temperature was measured for both Control cells 7.3 A and B and the FLB cells 5.1 and 5.2. The temperature was measured weekly using a bimetal thermometer permanently installed at either the gas header, metering station piping or gas well within each cell. Control cells 7.3 A and B both have two monitoring wells (referred to as 1 and 2), while each of the FLB cells, 5.1 and 5.2, has one. The results are graphically displayed in Figures 5-57 and 5-58.

The results available for this report span approximately 16 months from January 2002 until May 2003. Landfill gas temperature has remained steady throughout this period in both Control cells, as shown by the relatively level plots at each of the four monitoring points. The mean temperature varied between the monitoring wells, see Table 5-37.

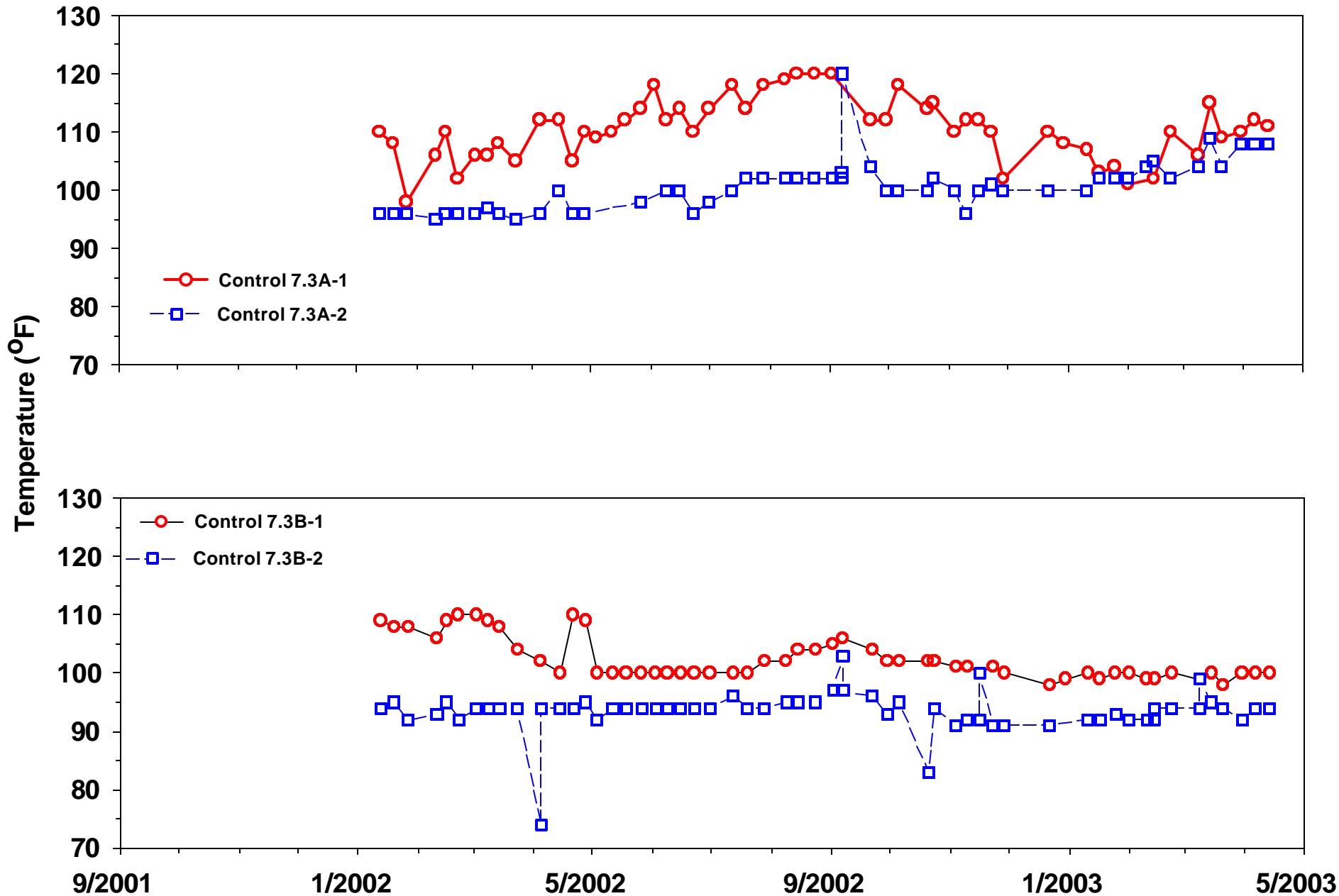
TABLE 5-37. SUMMARY OF LANDFILL GAS TEMPERATURES

Location	Approx. Mean Temperature (°F)	Max Temperature (°F)	Min Temperature (°F)
Control Cell A			
Monitoring Well 1	111	120	98
Monitoring Well 2	101	120* (108 typical)	95
Control Cell B			
Monitoring Well 1	102	110	98
Monitoring Well 2	94	102	75* (90 typical)

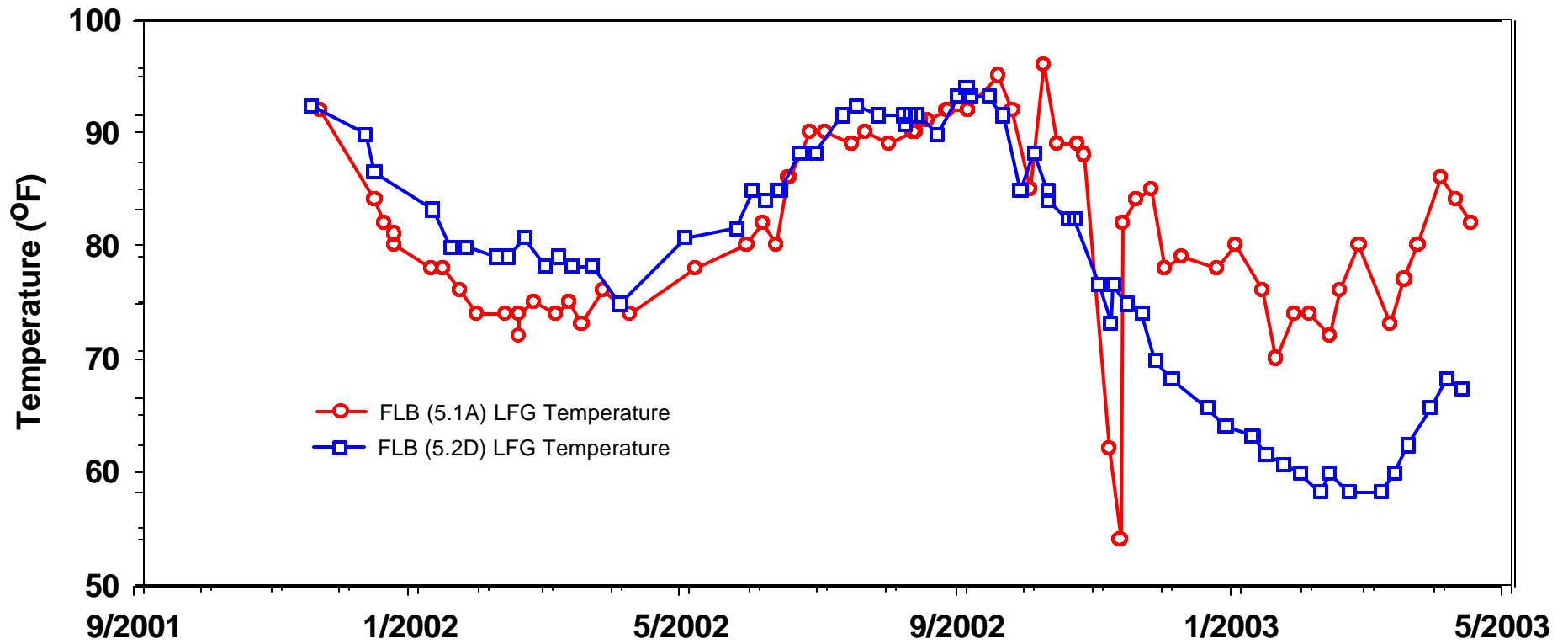
* Atypical value.

The results for the FLB, over approximately the same period, showed considerable variation in both cells throughout the period, although the overall trend for both cells was similar. Both cells showed a gradual decline in temperature until March 2002 from over 90°F to approximately 75-80°F. From March until September 2002, there was a gradual increase in LFG temperature to a maximum of about 95°F. This pattern was repeated with a decline in temperature over the Winter period until March 2003, when the temperature began to rise again. The minimum temperature reached in FLB 5.1 was approximately 72°F in January 2003 and 60°F in FLB 5.2 in February/March 2003.

Figure 5-57. Landfill Gas Temperature vs. Time for Control 7.3A and 7.3B



**Figure 5-58. Landfill Gas Temperature vs. Time for
FLB 5.1A and 5.2D**



Summary of Landfill Gas Composition

The landfill gas composition was measured for both Control cells 7.3 A and B and the FLB cells 5.1 and 5.2. The composition was measured weekly using the GEM 200 at the installed gas monitoring wells within each cell. Control cells 7.3 A and B both have two monitoring wells (referred to as 1 and 2), while each of the FLB cells, 5.1 and 5.2, has one. The results are graphically displayed in Figures 5-59, 5-60 and 5-61.

The bulk gas compositions for both Control Units, at both gas wells, remained constant for the period January 2002 until May 2003. The following table gives the approximate mean values for each component at each location. Results are summarized below in Table 5-38.

TABLE 5-38. SUMMARY OF LANDFILL GAS COMPOSITION IN THE CONTROL

Location	% Methane (v/v)	% Carbon Dioxide (v/v)	% Oxygen (v/v)
Control Unit A			
Monitoring Well 1	60	40	0
Monitoring Well 2	60	40	0
Control Unit B			
Monitoring Well 1	59	41	0
Monitoring Well 2	59	40	0

The bulk gas compositions in the FLB units showed greater variability over the period September 2001 until May 2003. However, results from Unit 5.1 were sufficiently consistent to justify calculating approximate mean values for the period. Gas composition is summarized below in Table 5-39.

TABLE 5-39. SUMMARY OF LANDFILL GAS COMPOSITION IN FLB5.1

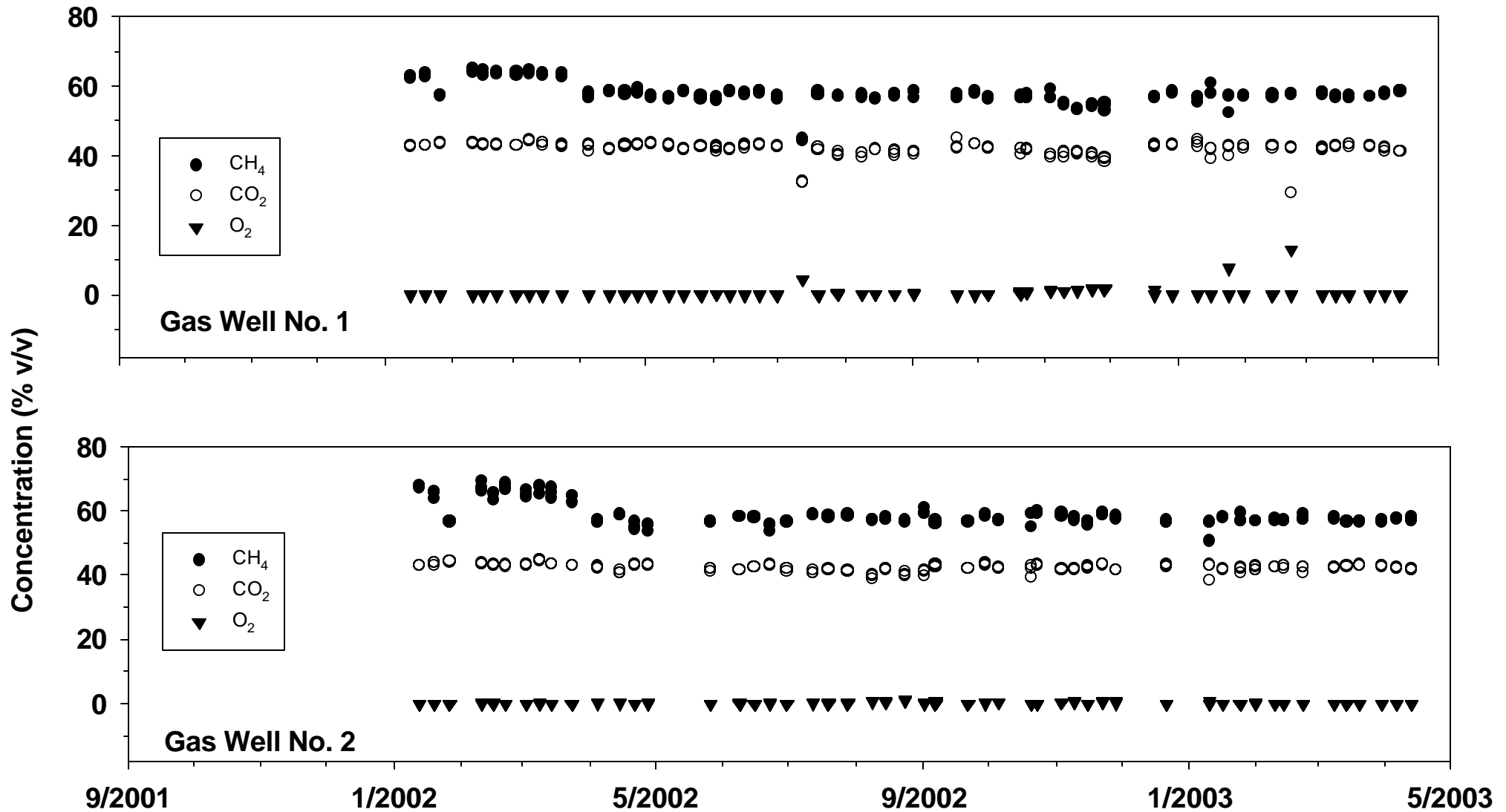
FLB Unit 5.1: Approximate Mean Gas Composition	
% Methane (v/v)	52
% Carbon Dioxide (v/v)	36
% Oxygen (v/v)	2

FLB Unit 5.2 bulk gas composition values were too variable after May 2002 to draw a meaningful average. The following table provides the maximum and minimum value recorded for each component over the period. Results are summarized below in Table 5-40.

TABLE 5-40. SUMMARY OF LANDFILL GAS COMPOSITION IN FLB 5.2

FLB Unit 5.2: Max and Min Gas Composition Values		
Component	Maximum % (v/v)	Minimum % (v/v)
Methane	62	20
Carbon Dioxide	47	4
Oxygen	17	0

Figure 5-59. Landfill Gas Composition vs. Time for Control 7.3A



**Figure 5-60. Landfill Gas Composition vs. Time for
Control 7.3B**

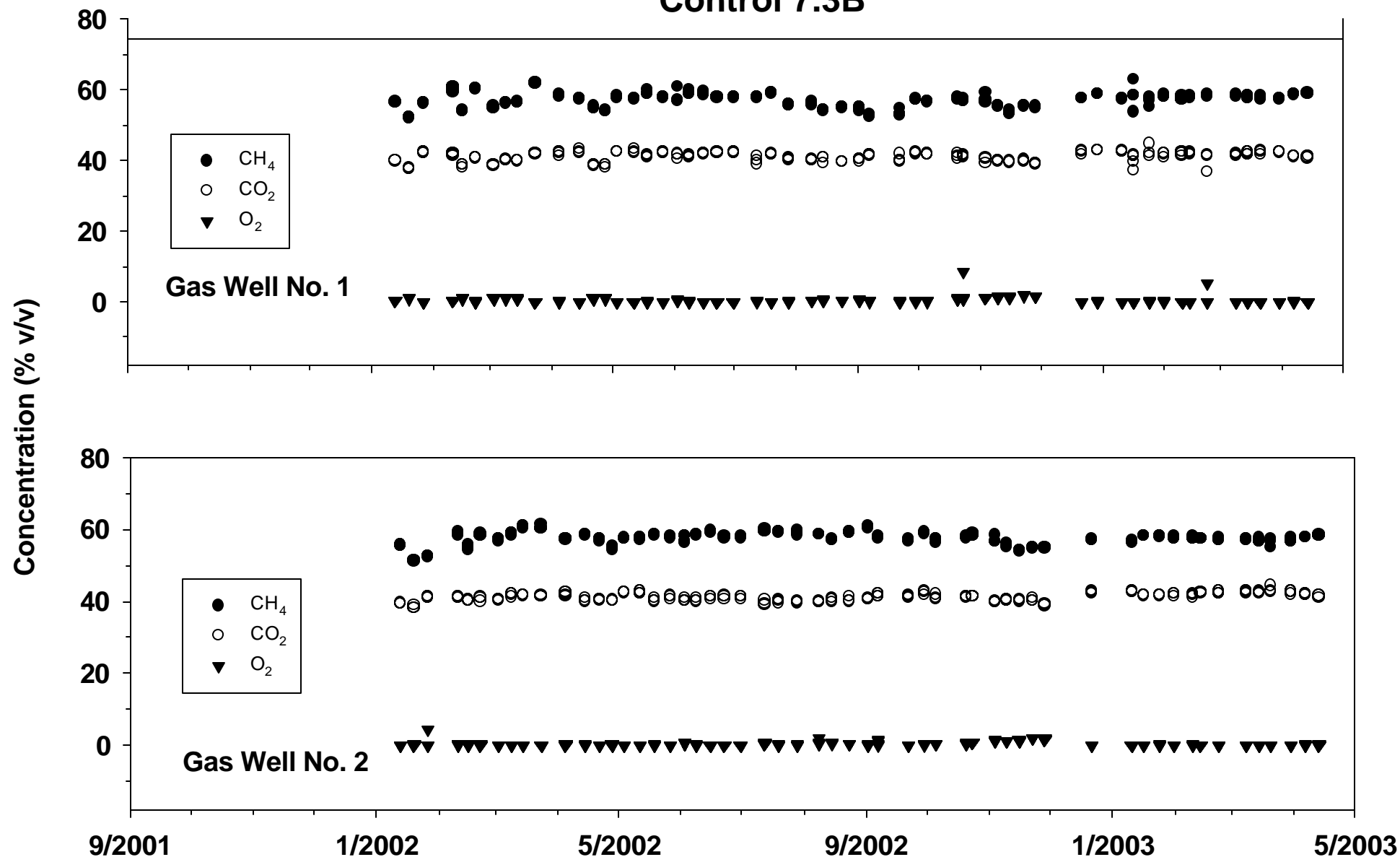
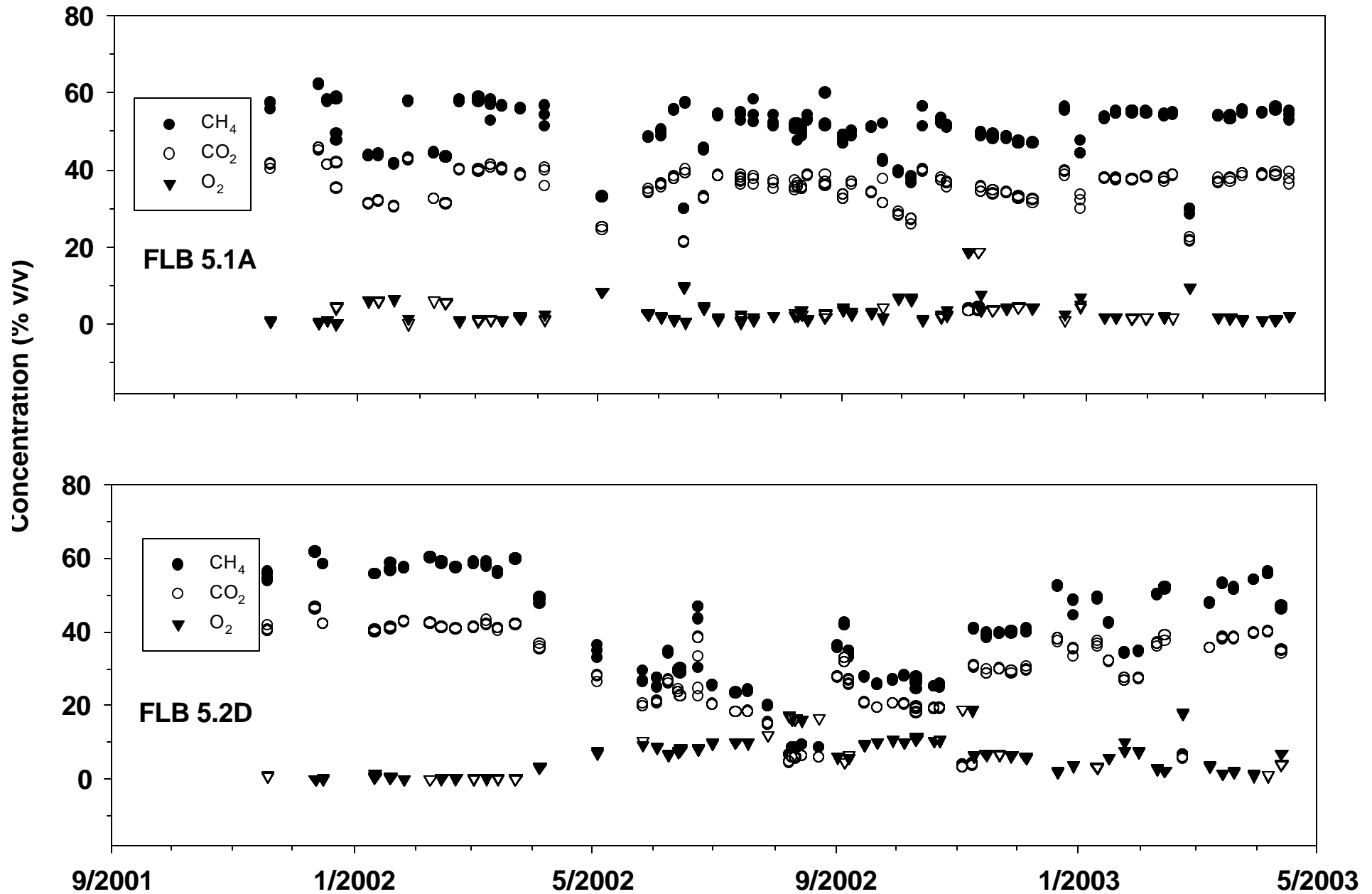


Figure 5-61. Landfill Gas Composition vs. Time for
FLB 5.1A and 5.2D



Summary of Landfill Gas Non-Methane Organic Compounds (NMOCs)

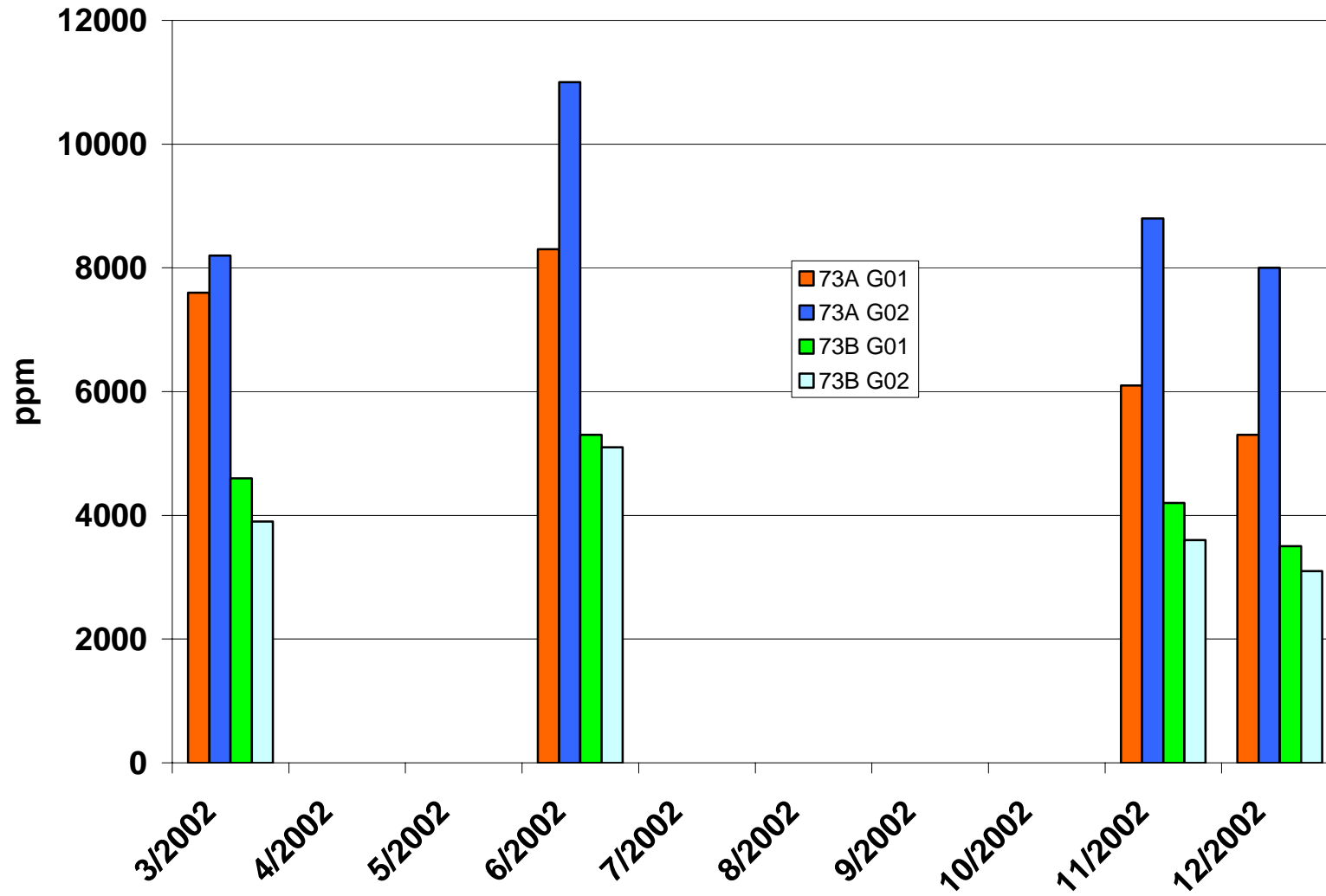
The landfill gas total NMOC content was measured for both Control cells 7.3 A and B and the FLB cells 5.1 and 5.2. The NMOC content was measured quarterly by extracting a LFG sample into a 6-liter SUMMA[®] canister from the installed gas monitoring wells within each cell, and submitting for off-site lab analysis. The results are displayed as bar charts in Figures 5-62 and 5-63.

Four samples were taken from each of the four monitoring wells in the Control units in March, June, November and December 2002. Five samples were taken from both monitoring wells in the FLB in December 2001, March, June, November and December 2002. The NMOC levels remained relatively constant, with significantly lower values seen in the FLB units. Results are summarized below in Table 5-41.

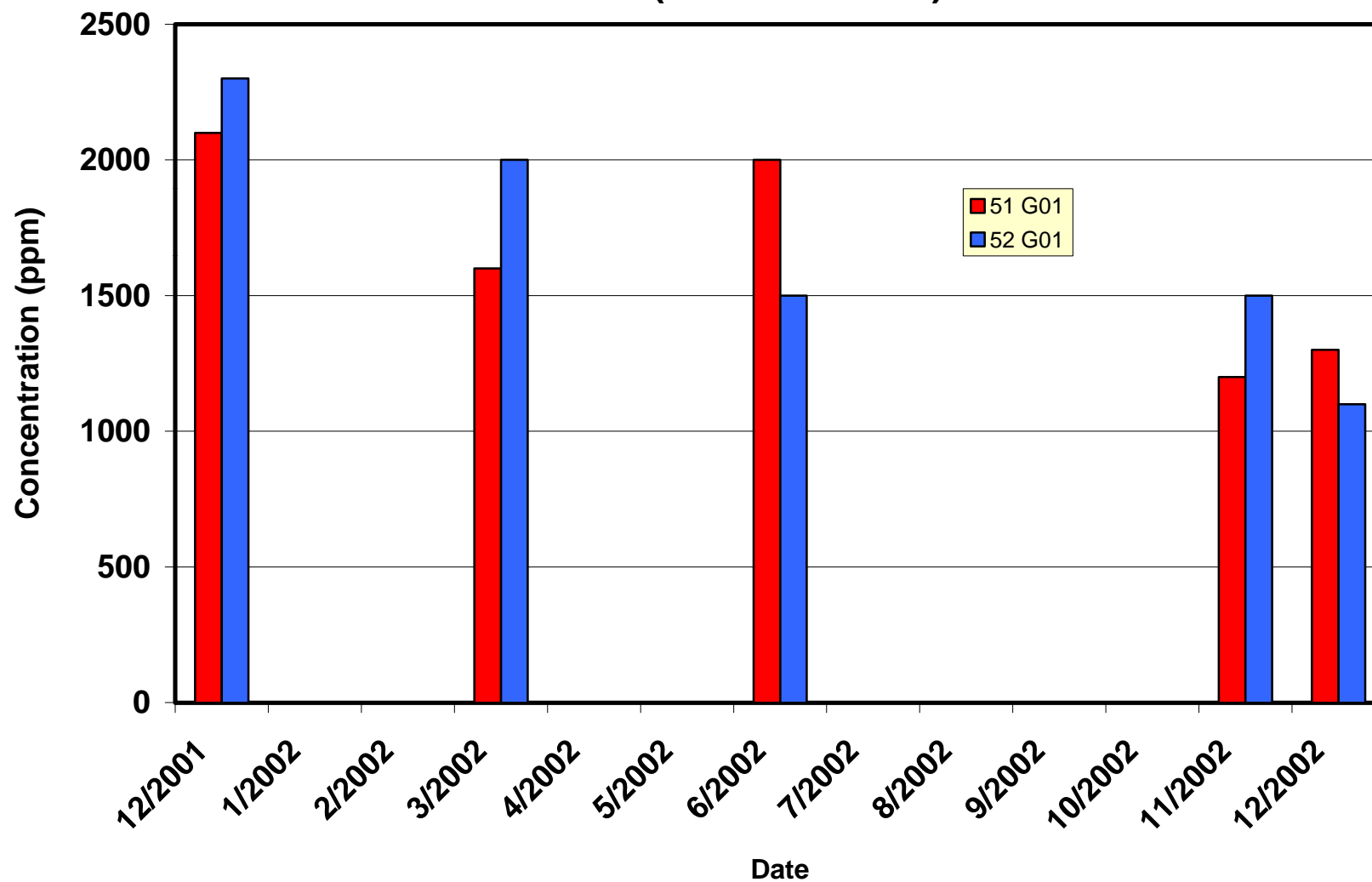
TABLE 5-41. SUMMARY OF LANDFILL GAS NMOCS

Maximum and Minimum Total NMOC Values Seen in Control and FLB Units		
<i>Location</i>	<i>Maximum Conc. (ppm-C, as hexane)</i>	<i>Minimum Conc. (ppm-C, as hexane)</i>
Control Unit 7.3A		
Gas Monitoring Well 1	1383	883
Gas Monitoring Well 2	1833	1333
Control Unit 7.3B		
Gas Monitoring Well 1	883	583
Gas Monitoring Well 2	850	517
FLB Unit 5.1		
Gas Monitoring Well	350	200
FLB Unit 5.2		
Gas Monitoring Well	383	183

**Figure 5-62. Total NMOCs vs. Time for
Control (7.3A & B)**



**Figure 5-63. Total NMOCs vs. Time for
FLB (5.1A and 5.2D)**



Summary of Landfill Gas Hazardous Air Pollutants (HAPs)

The presence of HAPs in LFG was measured for both Control cells 7.3 A and B, and the FLB cells 5.1 and 5.2. HAPs were measured quarterly by extracting a LFG sample into a 6-liter SUMMA[®] canister from the installed gas monitoring wells within each cell, and submitting for off-site lab analysis. The results are displayed as tables in Tables 5-42 through 5-45.

The readings for the Control units cover the period March 21, 2002 through December 19, 2002. The readings for the FLB units cover the period December 19, 2001 through December 19, 2002. For Control and FLB samples, HAPs were below detection limits in at least 64 percent of the samples.

TABLE 5-42. SUMMARY OF LANDFILL GAS HAZARDOUS AIR POLLUTANTS CONTROL 7.3A (GAS WELL 1 AND GAS WELL 2), MARCH 21, 2002 THROUGH DECEMBER 19, 2002

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-1000 µg/l	Number of Readings >1000 µg/l
Dichlorodifluoromethane	8	0	2	6
Chloromethane	8	8	0	0
1,2-Dichloro-1,1,2,2-tetrafluoroethane	8	6	2	0
Vinyl chloride	8	7	1	0
Bromomethane	8	8	0	0
Chloroethane	8	8	0	0
Trichlorofluoromethane	8	8	0	0
1,1-Dichloroethene	8	6	2	0
Carbon disulfide	8	8	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane	8	8	0	0
Acetone	8	0	0	8
Methylene chloride	8	4	3	1
Trans-1,2-Dichloroethene	8	8	0	0
1,1-Dichloroethane	8	8	0	0
Vinyl acetate	8	8	0	0
Cis-1,2-Dichloroethene	8	0	6	2
2-Butanone (MEK)	8	0	0	8
Chloroform	8	8	0	0
1,1,1-Trichloroethane	8	8	0	0
Carbon tetrachloride	8	8	0	0
Benzene	8	0	8	0
1,2-Dichloroethane	8	8	0	0
Trichloroethene	8	1	7	0
1,2-Dichloropropane	8	8	0	0
Bromodichloromethane	8	8	0	0
Cis-1,3-Dichloropropene	8	8	0	0
4-Methyl-2-pentanone (MIBK)	8	0	0	8
Toluene	8	0	0	8
Trans-1,3-Dichloropropene	8	8	0	0
1,1,2-Trichloroethane	8	8	0	0
Tetrachloroethene	8	0	3	5
2-Hexanone	8	8	0	0

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-1000 µg/l	Number of Readings >1000 µg/l
Dibromochloromethane	8	8	0	0
1,2-Dibromoethane (EDB)	8	8	0	0
Chlorobenzene	8	8	0	0
Ethylbenzene	8	0	0	8
Xylenes (total)	8	0	0	8
Styrene	8	0	0	8
Bromoform	8	8	0	0
1,1,2,2-Tetrachloroethane	8	8	0	0
Benzyl chloride	8	8	0	0
4-Ethyltoluene	8	0	0	8
1,3,5-Trimethylbenzene	8	0	2	6
1,2,4-Trimethylbenzene	8	0	0	8
1,3-Dichlorobenzene	8	8	0	0
1,4-Dichlorobenzene	8	4	2	2
1,2-Dichlorobenzene	8	8	0	0
1,2,4-Trichlorobenzene	8	8	0	0
Hexachlorobutadiene	8	8	0	0
Total	392	260	38	94

TABLE 5-43. SUMMARY OF LANDFILL GAS HAZARDOUS AIR POLLUTANTS CONTROL 7.3B (GAS WELL 1 AND GAS WELL 2), MARCH 21, 2002 THROUGH DECEMBER 19, 2002

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-1000 µg/l	Number of Readings >1000 µg/l
Dichlorodifluoromethane	8	8	2	6
Chloromethane	8	8	0	0
1,2-Dichloro-1,1,2,2-tetrafluoroethane	8	6	2	0
Vinyl chloride	8	1	2	5
Bromomethane	8	8	0	0
Chloroethane	8	8	0	0
Trichlorofluoromethane	8	7	1	0
1,1-Dichloroethene	8	8	0	0
Carbon disulfide	8	8	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane	8	8	0	0
Acetone	8	0	0	8
Methylene chloride	8	8	0	0
Trans-1,2-Dichloroethene	8	8	0	0
1,1-Dichloroethane	8	5	3	0
Vinyl acetate	8	8	0	0
Cis-1,2-Dichloroethene	8	0	4	4
2-Butanone (MEK)	8	0	0	8
Chloroform	8	8	0	0
1,1,1-Trichloroethane	8	8	0	0
Carbon tetrachloride	8	8	0	0
Benzene	8	0	5	3
1,2-Dichloroethane	8	8	0	0
Trichloroethene	8	0	8	0
1,2-Dichloropropane	8	8	0	0

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-1000 µg/l	Number of Readings >1000 µg/l
Bromodichloromethane	8	8	0	0
Cis-1,3-Dichloropropene	8	8	0	0
4-Methyl-2-pentanone (MIBK)	8	1	0	7
Toluene	8	0	0	8
Trans-1,3-Dichloropropene	8	8	0	0
1,1,2-Trichloroethane	8	8	0	0
Tetrachloroethene	8	0	5	3
2-Hexanone	8	8	0	0
Dibromochloromethane	8	8	0	0
1,2-Dibromoethane (EDB)	8	8	0	0
Chlorobenzene	8	8	0	0
Ethylbenzene	8	0	0	8
Xylenes (total)	8	0	0	8
Styrene	8	0	3	5
Bromoform	8	8	0	0
1,1,2,2-Tetrachloroethane	8	8	0	0
Benzyl chloride	8	8	0	0
4-Ethyltoluene	8	0	0	8
1,3,5-Trimethylbenzene	8	0	5	3
1,2,4-Trimethylbenzene	8	0	0	8
1,3-Dichlorobenzene	8	8	0	0
1,4-Dichlorobenzene	8	6	1	1
1,2-Dichlorobenzene	8	8	0	0
1,2,4-Trichlorobenzene	8	8	0	0
Hexachlorobutadiene	8	8	0	0
Total	392	258	41	93

**TABLE 5-44. SUMMARY OF LANDFILL GAS HAZARDOUS AIR POLLUTANTS
FLB 5.1(GAS WELL 1), DECEMBER 19, 2001 THROUGH DECEMBER 19, 2002**

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-100 µg/l	Number of Readings >100 µg/l
Dichlorodifluoromethane	5	0	5	0
Chloromethane	5	5	0	0
1,2-Dichloro-1,1,2,2-tetrafluoroethane	5	4	1	0
Vinyl chloride	5	0	4	1
Bromomethane	5	5	0	0
Chloroethane	5	5	0	0
Trichlorofluoromethane	5	5	0	0
1,1-Dichloroethene	5	5	0	0
Carbon disulfide	5	5	0	0
1,1,2-Trichloro-1,1,2,2-trifluoroethane	5	5	0	0
Acetone	5	0	0	5
Methylene chloride	5	3	2	0
Trans-1,2-Dichloroethene	5	5	0	0
1,1-Dichloroethane	5	4	1	0
Vinyl acetate	5	5	0	0
Cis-1,2-Dichloroethene	5	0	5	0
2-Butanone (MEK)	5	0	0	5

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-100 µg/l	Number of Readings >100 µg/l
Chloroform	5	5	0	0
1,1,1-Trichloroethane	5	5	0	0
Carbon tetrachloride	5	5	0	0
Benzene	5	0	5	0
1,2-Dichloroethane	5	5	0	0
Trichloroethene	5	2	3	0
1,2-Dichloropropane	5	5	0	0
Bromodichloromethane	5	5	0	0
Cis-1,3-Dichloropropene	5	5	0	0
4-Methyl-2-pentanone (MIBK)	5	0	4	1
Toluene	5	0	0	5
Trans-1,3-Dichloropropene	5	5	0	0
1,1,2-Trichloroethane	5	5	0	0
Tetrachloroethene	5	1	4	0
2-Hexanone	5	5	0	0
Dibromochloromethane	5	5	0	0
1,2-Dibromoethane (EDB)	5	5	0	0
Chlorobenzene	5	5	0	0
Ethylbenzene	5	0	0	5
Xylenes (total)	5	5	0	0
Styrene	5	3	2	0
Bromoform	5	5	0	0
1,1,2,2-Tetrachloroethane	5	5	0	0
Benzyl chloride	5	5	0	0
4-Ethyltoluene	5	0	0	5
1,3,5-Trimethylbenzene	5	0	5	0
1,2,4-Trimethylbenzene	5	0	0	5
1,3-Dichlorobenzene	5	5	0	0
1,4-Dichlorobenzene	5	0	5	0
1,2-Dichlorobenzene	5	5	0	0
1,2,4-Trichlorobenzene	5	5	0	0
Hexachlorobutadiene	5	5	0	0
Total	245	167	46	32

**TABLE 5-45. SUMMARY OF LANDFILL GAS HAZARDOUS AIR POLLUTANTS
FLB 5.2(GAS WELL 2), DECEMBER 19, 2001 THROUGH DECEMBER 19**

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-100 µg/l	Number of Readings >100 µg/l
Dichlorodifluoromethane	5	0	5	0
Chloromethane	5	5	0	0
1,2-Dichloro-1,1,2,2-tetrafluoroethane	5	4	1	0
Vinyl chloride	5	0	5	1
Bromomethane	5	5	0	0
Chloroethane	5	5	0	0
Trichlorofluoromethane	5	4	1	0
1,1-Dichloroethene	5	5	0	0
Carbon disulfide	5	5	0	0
1,1,2-Trichloro-1,2,2-trifluoroethane	5	5	0	0

HAPs Compounds	Number of Readings	Number of Non-Detects (ND)	Number of Readings 1-100 µg/l	Number of Readings >100 µg/l
Acetone	5	0	1	4
Methylene chloride	5	3	2	0
Trans-1,2-Dichloroethene	5	5	0	0
1,1-Dichloroethane	5	4	1	0
Vinyl acetate	5	5	0	0
Cis-1,2-Dichloroethene	5	0	5	0
2-Butanone (MEK)	5	0	1	4
Chloroform	5	5	0	0
1,1,1-Trichloroethane	5	5	0	0
Carbon tetrachloride	5	5	0	0
Benzene	5	0	5	0
1,2-Dichloroethane	5	5	0	0
Trichloroethene	5	1	4	0
1,2-Dichloropropane	5	5	0	0
Bromodichloromethane	5	5	0	0
Cis-1,3-Dichloropropene	5	5	0	0
4-Methyl-2-pentanone (MIBK)	5	0	3	2
Toluene	5	5	0	0
Trans-1,3-Dichloropropene	5	0	0	5
1,1,2-Trichloroethane	5	5	0	0
Tetrachloroethene	5	0	5	0
2-Hexanone	5	5	0	0
Dibromochloromethane	5	5	0	0
1,2-Dibromoethane (EDB)	5	5	0	0
Chlorobenzene	5	5	0	0
Ethylbenzene	5	0	0	5
Xylenes (total)	5	0	0	5
Styrene	5	3	2	0
Bromoform	5	5	0	0
1,1,2,2-Tetrachloroethane	5	5	0	0
Benzyl chloride	5	5	0	0
4-Ethyltoluene	5	0	0	5
1,3,5-Trimethylbenzene	5	0	5	0
1,2,4-Trimethylbenzene	5	0	0	5
1,3-Dichlorobenzene	5	5	0	0
1,4-Dichlorobenzene	5	0	5	0
1,2-Dichlorobenzene	5	5	0	0
1,2,4-Trichlorobenzene	5	5	0	0
Hexachlorobutadiene	5	5	0	0
Total	245	158	51	36

LANDFILL GAS SURFACE EMISSIONS

Methane emissions were measured on a twice-quarterly basis using a CEC-Landtec SEM-500 field instrument. Surface concentrations were monitored around the perimeter of the collection area and along a pattern that traversed the landfill at 30m intervals and where visual observations indicated elevated concentrations of landfill gas. Emissions were monitored and recorded separately for Unit 5 and 7.

The climatic conditions and the background methane concentration up and downwind were recorded for each sampling event. Background concentrations averaged 8.4 ppm upwind and 11.8 ppm downwind for Unit 5, and 5.0 ppm upwind and 8.2 ppm downwind for Unit 7, for the period December 2001 to July 2003.

Permit requirements necessitate a methane concentration greater than 500ppm above the measured background level to be marked, adjustments made to reduce the surface emissions at that location, and the location to be reanalyzed within 10 days. If an exceedance exists on reanalysis, additional adjustments and/or cover maintenance must be performed and the location reanalyzed within 10 days. On a third exceedance, the Air Pollution Control District (APCD) must be notified, and either a new well installed within 120 days of the initial exceedance, or an alternative remedy submitted for approval to the APCD.

During the period from December 2001 to July 2003, Unit 5 recorded the following permit response actions:

- Reported three occasions of exceedances which were resolved within 10 days via adjustment of the gas collection system;
- Five locations where additional soil cover was added; and
- Installation of one new gas collection well.

During the same monitoring period, Unit 7 recorded the following permit response actions:

- Seven locations where additional soil cover was added; and
- One occasion that required maintenance of the leachate risers to resolve the issue.

MOISTURE BALANCE

The moisture balance within the landfill is dependent on several factors, not all of which are known precisely. In conventional landfills, the primary moisture sources are precipitation and storm water runoff, along with other additions such leachate recirculation, LFG condensate, and waste moisture. The rate of percolation through the landfill, and ultimately the volume of leachate generated, is dependent in part on the nature of waste in the landfill and its field capacity. A moisture balance analysis will be performed for each of the test cells in the Final Report of this research investigation.

FUGITIVE GAS EMISSIONS

The AALB was found to have 160 g/s of methane, while the FLB unit was 39 g/s of methane. The AALB estimate is considered to be conservative since complete capture of the entire plume was not possible. Additional sampling is being conducted and will be combined with the September 2002 results. An overview of the fugitive gas emissions study is included in Appendix D.

SECTION 6

FIELD OBSERVATIONS

The purpose of this section is to summarize interim field observations made during the construction and operation of the Unit 5 and Unit 7 landfill bioreactor cells. These observations are from Mr. Tony Barbush, co-Principal Investigator, and Mr. Gary Hater, Project Manager, each an WMI employee with responsibilities for permitting, construction, and ongoing operations at the Outer Loop Facility. Selected photographs are provided in Appendix A to provide the reader with some insight of the site conditions and construction of project elements.

It is recognized that these observations are general in nature and are not supported by experimental field data as might be presented in a technical or scientific manner. Moreover, such observations may not be applicable at other landfill sites due to many variables.

Lack of supporting documentation and applicability might suggest that such observations should be excluded from this interim research report. However, full-scale trials of landfill bioreactor technologies are not common in the United States or in the published literature. Landfill owners and operators in the industry have little guidance as to what field techniques, practices, and procedures have merit with respect to the objectives of this and similar projects. As a result, this section has been included to contribute to the knowledge base of landfill operators seeking to explore the use of landfill bioreactor techniques and practices.

Four topics for field observation are discussed herein:

- Tire chips as part of cell construction
- Air addition to enhance aerobic degradation
- Landfill gas collection performance
- Moisture Addition Amounts

TIRE CHIPS AS PART OF CELL CONSTRUCTION

The use of tire chips was integrated into the construction of landfill bioreactor cells Units 5 and 7, generally for purposes of aggregate and replacement of gravel or stone where practical. During the cell construction period, WMI received over 20,000 tons of tire chips (less than 3-inch [1.935 mm²] pieces), equivalent to some 2.4 million tires, for pipe bedding, hydraulic separation of adjacent cells, and as part of a protection layer atop the leachate collection system.

As pipe bedding, the tire chips were placed into trenches as part of the installation of perforated pipe used for the reintroduction of air, leachate or other moisture, and for landfill gas collection. Depending on the cell, trenches were either 3-feet or 15-feet deep, with varying bedding layers, piping runs, and instrumentation installations. Field observations suggest that these tire chips work well for pipe bedding in terms of the intended design. Performance of the

tire chips may be reduced if there is significant vertical height of waste above the piping and subsequent compression loading. Field observations suggest that HDPE pipe SDR 17 (standard dimension ratio) performance is better when bedded in tire chips with less than approximately 75 feet of vertical waste height. This performance was confirmed, at least in part, through television inspection of such pipes (4-inch diameter) at the Outer Loop facility. At greater vertical waste heights, field observations suggest that either the bedding material must be changed (e.g., to gravel or glass cullet) or the piping must be changed to SDR 11.

In lieu of geomembranes or other impermeable materials, a 6- to 12-inch tire chip layer was used in conjunction with a 12-inch clay layer to construct hydraulic separation barriers between research cells. As the various cells were filled, this barrier was installed to retain leachate and infiltration moisture within the test cells, and to reduce/prevent landfill gas migration from other cells into the test cells.

A one-foot thick layer of tire chips was placed atop the leachate collection system as a protective material. This allowed the overall protective layer of placed refuse to be reduced to four feet from 10 feet.

AIR ADDITION TO ENHANCE AEROBIC DEGRADATION

The addition of air into Unit 7.4 was accomplished on an intermittent basis during the air addition phase of the program design. Landfill gas blowers were used primarily, along with an air compressor (or both) on some occasions. Rates of air addition into buried perforated pipe varied from approximately 200 scfm to 1,000 scfm, dependent on the waste lift and waste temperature, as well as on waste moisture and air permeability. For example, during the period of April 18, 2002 through April 1, 2003, lifts in Cell 7.4A were aerated for over 2,000 hours; lifts in Cell 7.4B were aerated for just over 600 hours, using only the blowers.

As discussed earlier in this report, significant attention was given to the placement and number of temperature probes. Even so, some 10 percent of the installed probes appeared to fail with time.

Waste temperature rise was used as a key measure to stop or reduce air addition. Field procedures called for evaluating continued air in the cells if any waste temperature probe reached 80° C, or if after reaching 60° C, a temperature probe increased by 10° C or more during any 48-hour period. Moisture additions were to be used, where warranted, to cool the in-place waste. Field observations and measurements suggested that these procedures avoided excessive temperatures that might lead to a subsurface fire situation. Over the period of treatment discussed herein, waste temperature exceedances did not occur and thus, aeration was not suspended nor was moisture addition prescribed for cooling the waste.

With the introduction of air into the landfill, no impacts were observed on fugitive landfill gas emissions. That is, no exceedances of regulatory thresholds were encountered before or after the period of aeration treatment from surface emissions monitoring.

LANDFILL GAS COLLECTION AND PERFORMANCE

Moisture additions called for in the program design appeared to have an impact on landfill gas collection performance. Significant LFG generation was able to be captured in the leachate risers, leading to the need to valve the riser vaults and cleanouts and improve overall collection. Horizontal landfill gas collectors appeared to work as designed; the exception to this was during rain surges where on occasion, the piping and bedding materials flooded temporarily. In Unit 5 where vertical wells were used, field experience indicated that the installation of in-place pumps was useful to prevent watering out of some landfill gas wells.

MOISTURE ADDITION AMOUNTS

Moisture additions called for in the program design were accomplished on an intermittent basis, dependent on several daily and seasonal factors, as well as operator judgments. Apparent moisture content of the as-received waste, moisture content of expected waste loads, received and forecasted precipitation, recent moisture additions (including leachate) and other considerations, were taken into account so as to achieve good waste infiltration while avoiding leachate outbreaks, seeps, and reduced performance of landfill gas collection wells due to excessive moisture.

Field observations on this project suggest that the removal of low permeability cover layers and paved haul roads prior to moisture addition can reduce or minimize sideslope seepage. In addition, placement of large volumes of non-permeable waste soils or similar materials should be directed away from the center of an operating cell, where practical, so as to manage moisture flow away from sideslopes.

Conceptually, a lower in-place waste density will allow greater volumes of moisture addition than a higher initial waste in-place density, other factors being equal. Field observations on this project suggest that this basic relationship holds. Consequently, basic guidance can be developed for moisture addition to in-place refuse when the initial in-place density can be calculated and the approximate area (footprint) of the cell is known.

This guidance is summarized in the below Figure 6-1, and provides a general calculated approach to the amount of moisture that can be added initially on a daily basis, relative to the surface area of the landfill cell. Based on field observations at the Outer Loop facility, moisture addition is an approximate linear relationship and not necessarily depth dependent. Note that a performance benchmark can be developed (termed the Airspace Utilization Factor, as discussed in Section 5) based on the calculated in-place waste density (wet) compared to the desired or target density (wet) to be achieved.

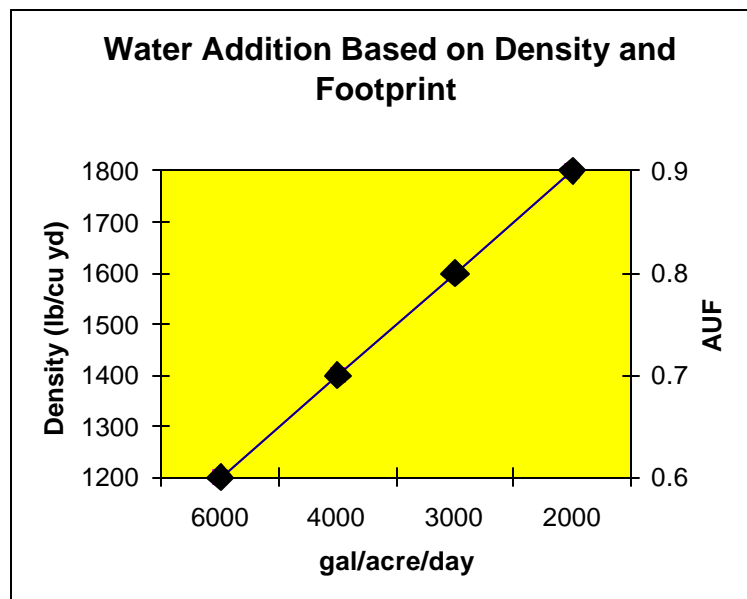


Figure 6-1. Water Addition Based on Density and Footprint

For example, suppose an operator intends to operate a new 10-acre landfill cell as a bioreactor through moisture addition and wetting of the waste at the working face. At the time of initial moisture addition, the calculated in-place density is approximately 1,400 lbs of refuse per cubic yard. Based on the above table, approximately 4,000 gallons per acre per day (or 40,000 gallons per day), can be added during dry working conditions at the onset. The field experience at the Outer Loop facility suggests this amount would not/did not result in leachate seeps or outbreaks. Moisture addition would be limited to the working face area, the operating deck, and/or, if installed, subsurface piping of some kind.

SECTION 7

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APPENDIX A

PROJECT PHOTOGRAPHS



Photo 1: Leachate Storage Tank



Photo 2: Drill Rig Equipped With a 3-foot Diameter Bucket Auger-Samples of Waste Are Collected in 10-foot Vertical Sections



Photo 3: Fresh Waste Sample Collected from Drill Rig Using a 3-foot Bucket Auger



Photo 4: Trenching Layout AALB Unit



Photo 5: Sequential Batch Reactor (SBR) Leachate Treatment Facility



Photo 6: Waste Temperature Measurements

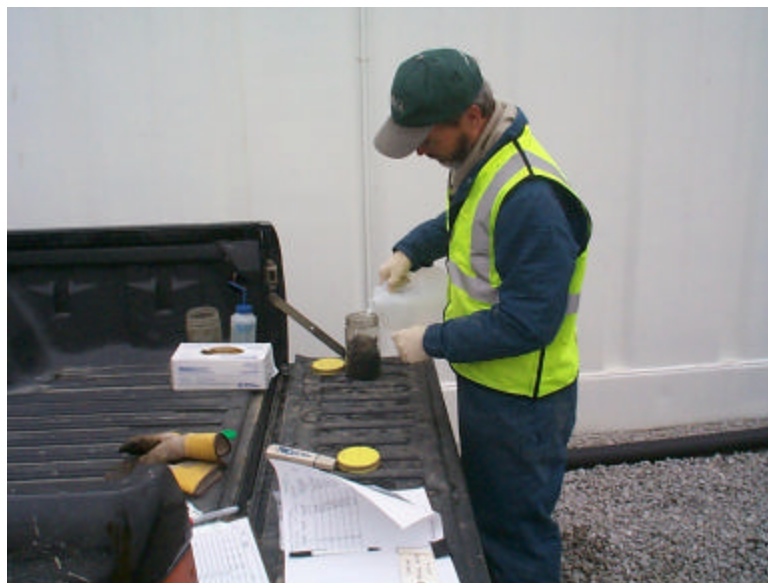


Photo 7: Leachate pH/Temperature /Conductance Sampling Using a Bench Top Accumet AR20 Instrument



Photo 8: Waste Sampling



Photo 9: Unit 5(FLB) Aerial Photograph



Photo 10: Unit 7 (AALB + Control) Aerial Photograph

APPENDIX B

QUALITY ASSURANCE PROJECT PLAN

**QUALITY ASSURANCE PROJECT PLAN FOR LANDFILL
BIOREACTOR STUDIES AT OUTER LOOP LANDFILL
LOUISVILLE, KENTUCKY**

Draft Final
November 2002

Prepared by:

Waste Management, Inc.
WMI Biosites Group
2956 Montana Ave
Cincinnati, OH 45211

and

Neptune and Company, Inc.
1505 15th Street, Suite B
Los Alamos, New Mexico 87544

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QUALITY ASSURANCE PROJECT PLAN DISTRIBUTION LIST

Wendy Davis-Hoover	EPA Project Co-Principal Investigator
Dave Carson	EPA Project Co-Principal Investigator
John Martin	EPA Project Manager
Fran Kremer	EPA Coordinator
Susan Thorneloe	EPA Scientist
Ann Vega/Scott Jacobs	EPA Quality Assurance Managers
Gary Hater	WMI Project Manager
Roger Green	WMI Co-Principal Investigator
Tony Barbush	WMI Co-Principal Investigator
Greg Cekander	WMI Senior Engineer
David Burt	WMI Contract Lab Quality Coordinator
Nancy Grams	WMI Quality Assurance
Morton Barlaz	NC State Scientist
Amy Haag	Severn Trent Project Manager
Charles Huber	Severn Trent QA Manager
Michael Goodrich	Microbial Insights Laboratory Manager
James Markwiese	Neptune and Company, Inc. QAPP Oversight

1.0 PROJECT DESCRIPTION

There are growing concerns about our ability to effectively manage municipal solid wastes. More wastes are being generated while it is becoming increasingly difficult to site space for new landfills (Tammemagi 1999). And wastes landfilled in the past are the source of many present-day human health and ecological concerns. We need innovative technologies to ensure that future waste management practices are sustainable and environmentally sound. Greater economical use of landfill space and more efficient gas and leachate management would be a positive step in this direction.

In large part, bacteria mediate waste degradation. This process is often moisture limited in a conventional landfill. Bioreactor landfills are designed to accelerate the biological stabilization of landfilled waste through leachate recirculation, thus enhancing the microbial decomposition of organic matter. Because waste stabilizes more quickly and likely to a greater extent than it would under conventional landfill operation, the receiving cell can accept more waste sooner and overall bioreactor landfill capacity should be greater. Enhanced waste stabilization should also reduce the potential for future environmental problems because the generation and subsequent attenuation of high-strength leachate occurs sooner than it would through conventional landfilling. In addition, bioreactor technology can reduce long-term requirements for monitoring gas migration and cover maintenance while minimizing the time required for profitable energy production through gas recovery (Arner 2002). Considering the potential environmental and economic benefits of bioreactor operations, there is great interest in this technology.

The bioreactor quality assurance project plan discussed here is under joint investigation by EPA and Waste Management, Inc., through a 5-year Cooperative Research and Development Agreement. The project is currently in its second year. The Outer Loop Landfill operated by Waste Management Inc., has been used for waste disposal for approximately 35 years. Two multi-year projects are underway at the site, including a Facultative Landfill Bioreactor (FLB) Study, and an Aerobic-Anaerobic Landfill Bioreactor (AALB) Study. At Outer Loop, treatment and control groups consist of separate and distinct landfill units, each composed of two paired cells. In contrast to many bioreactor demonstrations, these are large-scale projects. The FLB study covers approximately 19 ha (47 acres) in paired landfill cells that are generally 4 to 6 years of age and the AALB study covers 5 ha (12 acres) in paired one-year old landfill cells. The FLB cells are being retrofit for bioreactor operation whereas the bioreactor infrastructure in the AALB cells is constructed as waste is added. A separate unit of paired cells containing approximately 2- to 3- year old waste is used as the control for the FLB and AALB studies.

Because landfill units are filled sequentially (placement of waste in a particular cell is only initiated after the current waste-receiving cell is completely filled), individual units in this study are not directly comparable with respect to time. It is assumed that the control cells will provide an adequate treatment reference by considering them as temporally offset from the treatment cells. For example, consider the comparison between FLB cells and the control. As mentioned, FLB waste is generally 4-6 years old and control waste is about 2-3 years old. In three years, control waste will be approximately the same age as present-day FLB waste. Therefore, control

samples collected three years following the initiation of the FLB treatment should represent the FLB cells as they were when leachate was first introduced.

1.1 Facultative Landfill Bioreactor (FLB) Study

1.1.1 FLB Primary Objective The primary objective is to evaluate waste stabilization and settlement resulting from nitrate-enriched leachate application to test cells 5 North and 5 South relative to waste stabilization in control cells 7.3A and 7.3B. Details on the evaluation of this Primary Objective are presented in Section 3.2.

1.1.2 FLB Secondary Objective The secondary objective is to assess nitrogen dynamics associated with the application of nitrate-enriched leachate to an existing landfill. Because there is no representative control for evaluating the effects of nitrate in isolation (i.e., an equivalent system receiving leachate that has not been enhanced with nitrate), these results will be recorded for potential use in future studies.

1.1.3 FLB Project Description Waste Management, Inc. (WMI) proposes to test the efficacy of accelerating the stabilization of waste within the landfill by injecting nitrate-containing leachate into an existing landfill cell. This approach is based on two premises. The first, which is generally accepted, is that the addition of leachate will moisten and promote degradation of the waste. The second is that microorganisms present in the landfill waste will use nitrate in the leachate as a terminal electron acceptor for anaerobic metabolism. As nitrate containing liquid moves through the upper sections of the FLB, denitrifying bacteria convert nitrate to dinitrogen gas (Appendix B). This transformation of nitrate-nitrogen to gaseous nitrogen should result in a net loss of nitrogen from the landfill.

1.1.4 FLB Process Description A series of horizontal trenches will be installed up to 18 feet below the surface in cells 5 North and 5 South. Each trench will contain a perforated pipe and will be back filled with a permeable material (e.g., tire chips). The trenches will be spaced approximately sixty feet apart. Six vertical gas extraction wells (twelve total) will also be constructed in cells 5 North and in 5 South. The gas wells will serve the dual purpose of collecting landfill gas and penetrating layers of soil cover placed during landfilling. Probes for measuring temperature and oxidation-reduction potential will be installed during gas well construction. Similar installations will be made for the 7.3A and 7.3B control cells.

The FLB will be enhanced with leachate that has used chemolithotrophic bacteria to take NH_4^+ to NO_3^- in the aerobic Sequential Batch Reactor, then the denitrifying bacteria under anaerobic conditions in the landfill will use the NO_3^- as a terminal electron acceptor to form both N_2O and N_2 gasses. This nitrified leachate will be introduced to the waste through the series of horizontal trenches that will be installed in cell 5 North and in cell 5 South. The treated SBR effluent is monitored on a monthly basis for COD, BOD, ammonia-nitrogen, nitrite/nitrate nitrogen and phosphorus. The treated leachate will be pumped to a holding tank and distributed to the trenches via a force main and manifold for distribution to the FLB. Liquid sources other than

leachate, such as water from the Outer Loop under drain or sedimentation pond, or other liquid waste streams as permitted by regulation, may be used to augment the supply of leachate. These liquid sources will be monitored in the same way as the SBR effluent in order to follow nitrogen dynamics. Liquid will be added in the volume necessary to achieve and maintain the in-place waste at a moisture level of 35-55%.

Leachate analyses will be taken to evaluate the effect of liquid addition on the MSW. Changes in leachate parameters are expected to broadly represent the changes in the MSW. Specifically, the impact of nitrified effluent applied to the landfill in Area 5 and subsequent denitrification should impact the overall mass balance of nitrogen as the nitrate is converted to nitrogen gas. The data collected for COD, BOD, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen, as well as leachate quantification (e.g., production, head on liner; Table 3-1) will be examined as the project progresses.

1.2 Aerobic-Anaerobic Landfill Bioreactor (AALB) Study

1.2.1 AALB Primary Objective The primary objective is to evaluate waste-stabilization enhancement resulting from the sequential establishment of aerobic and anaerobic conditions in cells 7.4A and 7.4B relative to waste stabilization in the control cells 7.3A and 7.3B. Details on the evaluation of this Primary Objective are presented in Section 3.2.

1.2.2 AALB Secondary Objective The secondary objective is to demonstrate the feasibility of implementing an AALB on a commercially viable operating scale. Details on the evaluation of this Secondary Objective are presented in Section 3.2.

1.2.3 AALB Project Description The proposed Aerobic-Anaerobic Landfill Bioreactor (AALB) study will examine the impact that establishing sequential aerobic and anaerobic conditions has on accelerating waste stabilization. In this scheme waste is treated aerobically, similar to composting, by injecting air into the waste for approximately 45 days. After aeration is discontinued, the waste is moistened with liquids, and anaerobic conditions are rapidly established. The rationale behind this sequential approach is to promote the rapid decomposition of food waste and other easily degradable organic matter in the aerobic stage of treatment with the intent of reducing the amount of fermentable organic matter entering the anaerobic stage. This could shorten the acid generating phase of anaerobic waste decomposition and result in a more rapid onset of methanogenesis. WMI has operated an experimental AALB at its Metro RDF landfill located in Franklin, Wisconsin since October 1999. The Metro RDF experience suggests that waste density (i.e., waste compaction) increases relatively rapidly as a result of aeration.

1.2.4 AALB Process Description The base layer of waste will be a liner protection layer (loose waste) placed in cells 7.4A and 7.4B that is not compacted. Cells 7.4A and 7.4B will be constructed in fifteen-foot vertical lifts. This shallow lift system results from grading the waste to promote homogenization of the incoming solid waste (shearing of large materials and breaking open trash bags). As each lift is completed, water is added to increase the moisture content of the waste. Perforated pipes are placed at regular intervals across the top surface of the waste. The

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pipes are covered with a permeable media such as tire chips or aggregate. Each lift of piping is connected via a common manifold. The next lift of waste is then placed over the installed piping. This construction sequence is repeated for successive lifts of waste.

The installed piping serves three functions: the injection of air; the injection of water; and the extraction of gas. In the proposed configuration, the uppermost lift of the landfill is aerated. The lift immediately below this lift receives water, while landfill gas is extracted from all deeper lifts. Probes for measuring temperature and oxidation-reduction potential will be installed during the construction of cells 7.4A and 7.4B. Settlement of the test and control cells will be measured using global positioning system (GPS; Trimble model 4800) equipment and taking quarterly surveys of 20 (or 40 in cells 5N and 5S) survey points in each cell.

1.3 Landfill Bioreactor Study Schedule The FLB areas will be monitored for a period of 5 years. The AALB study area (7.4A and 7.4B) is scheduled for 3 years of monitoring. The installation of the horizontal trenches and in-place monitoring equipment should be complete by the end of 2001. The time line for the Outer Loop Landfill bioreactor studies is presented in Appendix A.

1.4 Overview of Data Collection Measurements will be collected from three media for each study: liquid (leachate), gas, and solid waste. Depending upon the medium and analyte or characteristic, samples will be collected on an annual, monthly, quarterly, weekly, or daily basis. Leachate will be collected from a sump for each cell. Gas will be collected from a gas collection point in a cell. The solid waste in each cell will be sampled through boring and GPS measurements of elevation. Field measurements of rainfall and temperature will be recorded regularly and historical records will also be consulted to account for inter-year variability of parameters such as rainfall and temperature.

2.0 PROJECT ORGANIZATION

Key personnel for this project are identified along with their roles and responsibilities in Tables 2-1 and 2-2. The overall project is being managed, analyzed and operated by Waste Management, Inc. at the Outer Loop Landfill located in Louisville, KY. The personnel will be made up of individuals from Outer Loop and the WMI BioSites program in Cincinnati, OH. The U.S. EPA is contributing to the oversight and analysis of the project. Details on the parties responsible for analytical measurements are presented in Section 5.1, Table 5-1.

2.1 Quality Assurance Management Team David Burt manages the formal audit and quality assurance program for WMI contract labs. David Burt will model field wet chemistry analysis and university analyses to match the corporate contract lab testing protocols. Nancy Grams will function as the QA manager for this project and serve as a laboratory auditor and data validator. Ann Vega, EPA's quality assurance manager, is responsible for endorsing the QAPP for the quality assurance branch, while David Carson and Wendy Davis-Hoover are responsible for approving the QAPP. Jim Markwiese is responsible for tracking revisions to the QAPP and for keeping the QAPP current.

Table 2-1. QA Management Team

Personnel, title	Phone	Email
David Burt, <i>WMI contract lab quality coordinator</i>	(713) 533 5000	dburt@wm.com
Nancy Grams, <i>WMI quality assurance, data validation</i>	(847) 464-1123	nancygrams@aol.com
Ann Vega, <i>EPA quality assurance manager</i>	(513) 569-7635	vega.ann@epa.gov
Scot Jacobs, <i>EPA quality assurance manager</i>	(513) 569-7223	jacobs.scott@epa.gov
David Carson, <i>EPA Co-Principal Investigator</i>	(513) 569-7527	carson.david@epa.gov
Wendy Davis-Hoover, <i>EPA Co-Principal Investigator</i>	(513) 569-7206	davis-hoover.wendy@epa.gov
Jim Markwiese, <i>Neptune and Company, Inc.</i>	(505) 662-2121	jimm@neptunenandco.com

In addition to this QAPP, USEPA is performing microbial analyses on the waste and biocover research is underway at this site. Both of these efforts are addressed in addenda to this QAPP.

2.2 Responsibilities of Other Project Participants

Table 2-2. Project Participant List

Name	Project Title	Responsibilities
Wendy Davis-Hoover*	EPA Project Co-Principal Investigator	EPA Project Investigator
Dave Carson*	EPA Project Co-Principal Investigator	EPA Project Investigator
John Martin*	EPA Branch Chief	Project Oversight/Management
Fran Kremer*	EPA Coordinator	Project Coordination
Susan Thorneloe*	EPA Scientist	Technical Consultation, Air

Table 2-2. Project Participant List, con't.

Name	Project Title	Responsibilities
Gary Hater*	WMI Project Manager	Manage Project for WMI
Tony Barbush*	WMI Co-Principal Investigator	Permits & Construction
Douglas Goldsmith*	WMI Senior Scientist	Sampling and Analysis of Waste Matrices
Greg Cekander*	WMI Senior Engineer	Engineering and Design Issues
Chuck Williams	WMI Program Owner	Program Owner
Jim Norstrom	WMI Program Administrator	Goal Manager and Owner
Roger Green*	WMI Co-Principal Investigator	Field Sampling Oversight & Database Management
David Burt	WMI contract lab quality coordinator	Quality Assurance Oversight for Barlaz Lab
Amy Haag	Severn Trent Project Manager	Leachate and Select Gas Analyses
Charles Huber	Severn Trent QA mgr.	Quality Assurance Oversight for Severn-Trent Laboratory
Morton Barlaz	North Carolina State University Scientist	Solid Waste Analytical Measurements and Laboratory Quality Assurance
Michael Goodrich	Microbial Insights	Laboratory Mgr.
Jim Markwiese*	Neptune & Company Scientist	EPA QAPP Coordinator

* Primary participants

There are eleven primary participants and two participating laboratories in this project. WMI plans to have a minimum of one Bioreactor meeting a year at Outer Loop and participation by Primary Participants will be at least at the 80% level. Quarterly review meetings are also planned by WMI.

Table 2-3. Contact Information: Primary Project, Quality Assurance and Contract Laboratory Personnel

Name	Title	Address	Phone	E-mail
Wendy Davis-Hoover	EPA Project Co-Lead	US EPA 5995 Center Hill Ave Cincinnati, OH 45224	(513) 569-7206	davis-hoover.wendy@epamail.epa.gov
Dave Carson	EPA Project Co-Lead	US EPA 5995 Center Hill Ave Cincinnati, OH 45224	(513) 569-7527	carson.david@epamail.epa.gov
John Martin	EPA Branch Chief	US EPA 5995 Center Hill Ave Cincinnati, OH 45224	(513) 569-7758	martin.johnf@epamail.epa.gov
Fran Kremer	EPA Coordinator	US EPA 26 West MLK Dr Cincinnati, OH 45224	(513) 569-7346	kremer.fran@epamail.epa.gov
Susan Thorneloe	EPA Scientist	US EPA AAPCD Mail Drop 63 Research Triangle Park, NC 27711	(919) 541-2709	thorneloe.susan@epamail.epa.gov

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Table 2-3. Contact Information: Primary Project, Quality Assurance and Contract Laboratory Personnel, con't.

Name	Title	Address	Phone	E-mail
Tony Barbush	WMI District Engineer Co-Principal Investigator	Waste Management 7501 Grade Lane Louisville, KY 40219-3547	(502) 962-5069	tbarbush@wm.com
Gary Hater	WMI BioSites Program Director/Project Manager	Waste Management 2956 Montana Ave Cincinnati, OH 45211	(513) 389-7370 ext. 19	ghater@wm.com
Roger Green	WMI Senior Scientist/Co-Principal Investigator	Waste Management 2956 Montana Ave Cincinnati, OH 45211	(513) 389-7370 ext. 18 FAX (513) 389-7374	rgreen2@wm.com
David Burt	WMI Lab QA Mgr	155 N. Redwood Dr.; Suite 250; San Rafael, CA 94903	(415) 479-3700	dburt@wm.com
Greg Cekander	WMI Senior Engineer	Waste Management 1001 Fannin, Suite 4000 Houston, Texas 77002	(713) 533-5004	gcekander@wm.com
Douglas Goldsmith	ANT President/WMI Senior Scientist	Alternative Natural Technology 1847 Whittaker Hollow Rd. Blacksburg, VA 24060	(540) 552-3684	doug@infi.net
Nancy Grams	WMI QA Mgr, Lab Auditor	40 W. 840 Rosebend Elgin, IL 60123	(847) 464-1123	nancygrams@aol.com
Morton Barlaz	North Carolina State University Scientist/ QA mgr.	Dept. Civil Engineering 203-B Mann Hall, Box 7908 North Carolina State University Raleigh, North Carolina 27695	(919) 515-7676	barlaz@eos.ncsu.edu
Charles Huber	Severn Trent QA mgr.	Severn Trent Services-STL 10 Hazelwood Dr., Suite 106 Amherst, NY 14228	(716) 691-2600	chuber@stl-inc.com
Amy Haag	Severn Trent Project Manager	Severn Trent Services-STL 10 Hazelwood Dr., Suite 106 Amherst, NY 14228	(716) 691-2600	ahaag@stl-inc.com
Michael Goodrich	Microbial Insights Laboratory mgr.	Microbial Insights 2340 Stock Creek Blvd. Rockford, TN 37853-3044	(865) 573-8188	gooch@microbe.com
Jim Markwiese	Neptune & Company Scientist	Neptune and Company, Inc. 1505 15 th Street, Suite B Los Alamos, NM 87544	(505) 662-2121	jimm@neptuneinc.org

3.0 EXPERIMENTAL APPROACH

3.1 Sampling Strategy The primary objective of sampling the control, FLB, and AALB is to determine the impact of waste stabilization as a result of treatment applications relative to an untreated control. The number and type of each analysis is extensive and presented in Tables 3-1, 3-2 and 3-3 for leachate, municipal solid waste and gas, respectively, for year one. Leachate samples for control areas 7.3A and 7.3B are taken from under the drain sump area. The landfill study areas (5N and 5S) and (7.4A and 7.4B) are sampled similarly. Diagrams of sampling locations for each matrix will be provided as a separate attachment from WMI on an “as needed” basis (Appendix H). Justification for the sample parameters is presented in Sections 1 and 3.2.

Table 3-1. Leachate Sampling Schedule for Outer Loop Bioreactor Studies

Collection Frequency and Parameter	Number of Samples to be Collected During the First Year per Cell					
	FLB 5 N	FLB 5 S	Control 7.3A	Control 7.3B	AALB 7.4A	AALB 7.4B
Continuous						
Head on liner Leachate production						
Monthly						
Chemical oxygen demand	12	12	12	12	12	12
Biochemical oxygen demand	12	12	12	12	12	12
Ammonia-nitrogen (NH ₃ -N)	12	12	12	12	12	12
Ortho P / Total P	12	12	12	12	12	12
Nitrate-nitrogen (NO ₃ -N)	12	12	12	12	12	12
Nitrite-nitrogen (NO ₂ -N)	12	12	12	12	12	12
Total volatile organic acids	12	12	12	12	12	12
Temperature	12	12	12	12	12	12
pH	12	12	12	12	12	12
Quarterly						
VOC	4	4	4	4	4	4
SVOC	4	4	4	4	4	4
Total Kjeldahl Nitrogen	4	4	4	4	4	4
Total dissolved solids	4	4	4	4	4	4
Sulfate	4	4	4	4	4	4
Chloride	4	4	4	4	4	4
Potassium	4	4	4	4	4	4
Conductance	4	4	4	4	4	4
RCRA hazardous metals	4	4	4	4	4	4

Table 3-2. Municipal Solid Waste Sampling Schedule for Outer Loop Bioreactor Studies*

Collection Frequency and Parameter	Number of Samples to be Collected During the First Year per Cell					
	FLB 5 N	FLB 5 S	Control 7.3A	Control 7.3B	AALB 7.4A	AALB 7.4B
Daily						
Oxidation Reduction Potential	250	250	250	250	250	250
Temperature	250	250	250	250	250	250
Quarterly						
Waste Settlement (GPS)	40 pts**	40 pts**	20 pts	20 pts	20 pts	20 pts
Annually						
Cellulose/lignin	30	30	30	30	30	30
Organic solids	30	30	30	30	30	30
Biochemical Methane Potential	30	30	30	30	30	30
Annually						
Waste Moisture	30	30	30	30	30	30
Waste Density	30	30	30	30	30	30
Appearance	30	30	30	30	30	30
pH	30	30	30	30	30	30

* Given the extension of the originally anticipated start date of the project, solid waste sampling will not begin until 2002.

** 5 North and 5 South are each comprised of two subcells, with each subcell having 20 GPS points.

Table 3-3. Gas Sampling Schedule for Outer Loop Bioreactor Studies

Collection Frequency and Parameter	Number of Samples to be Collected During the First Year per Cell					
	FLB 5 N	FLB 5 S	Control 7.3A	Control 7.3B	AALB 7.4A	AALB 7.4B
Weekly						
Landfill gas flow/production	52	52	52	52	52	52
CH ₄ , CO ₂ , O ₂	52	52	52	52	52	52
Quarterly						
CH ₄ , CO ₂ , O ₂ , Summa canister	4	4	4	4	4	4
Nonmethane organic carbon (NMOC)	4	4	4	4	4	4
Hazardous Air Pollutants (HAPs)	4	4	4	4	4	4
Surface emission monitoring (CH ₄) ¹	4	4	4	4	4	4

¹ Surface emission monitoring will be performed twice quarterly .

While the sampling schedule (Tables 3-1 through 3-3) is presented in a maximum time frame of one year, the proposed research will extend for many years. As shown in Appendix A, data collection activities are planned well beyond 2003. After the first year, the QAPP may be modified (with agreement from all parties) in an effort to utilize resources more efficiently. Unless strong justification can be made for changing the frequency of sampling and other research issues, however, the plan outlined in the QAPP will hold from year to year.

3.2 Critical and Non-Critical Measurements Landfilled waste typically progresses through five phases of degradation, including: (1) adjustment or acclimation; (2) transition; (3) acidogenesis; (4) methanogenesis; and (5) maturation (Reinhart and Townsend 1998). This degradation process can be collectively considered as waste stabilization. At any given time, landfill cells may be characterized as experiencing one of the above phases. But because waste is deposited in a landfill cell over time (months to years), waste-stabilization phases tend to overlap and sharp boundaries between phases are not typical. It is expected, however, that the bioreactor treatments will increase the rate of transition through the various phases relative to the control. It is further expected that this enhanced transition to stabilized waste will be discernable with trend analyses. The critical measurements (*italicized*) employed in this study were selected to capture aspects of waste stabilization over time.

2. **Acclimation.** During acclimation, microbial populations are in a state of adjustment. Waste moisture tends to increase and available oxygen is consumed during this phase. The atmospheric-oxygen supply to the buried waste is diffusion limited and outpaced by the oxygen demand of bacterial respiration; consequently the concentration of oxygen in the landfill cell begins to decrease.
6. **Transition.** In the transition phase, conditions turn anaerobic as the available oxygen is consumed through the metabolism of readily degradable wastes. Complex organic matter is broken into simpler forms (e.g., organic acids) and energy that is not captured by cells during respiration is given off as heat. Waste and leachate temperature concomitantly increase during organic-matter degradation. Other respiration by-products (carbon dioxide and volatile organic acids) begin to increase in leachate.
7. **Acidogenesis.** During acidogenesis the accumulation of volatile organic acids reaches its peak due to metabolism and fermentation of organic matter. The increase in chemical oxygen demand and biochemical oxygen demand indirectly reflects this increase in degradable metabolites. In addition, the high concentration of acids increases hydrogen ion activity, reflected by decreased waste and leachate pH. In the near absence of oxygen, metabolism shifts to anaerobic bacteria capable of utilizing alternate electron acceptors (e.g., nitrate and sulfate).
8. **Methanogenesis.** In the methanogenic phase, the supply of most electron acceptors is exhausted. Methanogenic bacteria ferment organic acids to methane and carbon dioxide while other methanogens utilize CO₂ as their terminal electron acceptor. Consequently, gas (methane and CO₂) volume and production rates increase. Anaerobic respiration is a proton-consuming process and this is reflected by an increase in pH values in the waste and leachate.
9. **Maturation.** The maturation phase represents the end-point of landfill settlement (surface GPS measurements). The overall conversion of complex wastes to leachable organic acids and gaseous products also serves to reduce the waste volume and organic solids and to increase waste density. Maturation occurs when degradable organic matter, and consequently microbial growth, is limited. This is reflected by decreases in the biochemical methane potential and gaseous metabolic by-products methane and CO₂. Concentrations of organics in leachate remain steady but at substantially reduced levels relative to earlier phases.

In addition to the biological and chemical parameters listed, settlement of the test and control cells will be measured by a professional surveying team by taking quarterly readings of 40 to 80 global positioning system points in each treatment. The critical measurements listed above directly support the primary project objective of evaluating waste stabilization.

There are also many secondary measurements for each matrix including 17 additional parameters for leachate, 3 for solid waste and 3 for gas. These non-critical measurements primarily support secondary project objectives (e.g., documentation of nitrogen dynamics, Section 1.1.2) and tangentially support primary project objectives. The FLB Secondary Objective is described in Section 1.1.2. To address the AALB Secondary Objective (Section 1.2.2), information on estimated investment, operating revenue, and operating costs will be collected on the AALB process in cells 7.4A and 7.4B. Once the information-gathering stage is complete, data will be analyzed in an economic model previously created in Microsoft Excel. The functionality and format of the model allows for estimations of life-of-site income statements, statements of cash flow, and financial-ratio calculations to evaluate the feasibility of implementing the AALB process at a commercially viable operating scale. Critical and non-critical parameters are identified in Tables 3-4, 3-5 and 3-6.

Table 3-4. Critical and Non-critical Measurements for Leachate

CRITICAL	NON-CRITICAL
Chemical oxygen demand	VOC (Volatile Organic Compounds)
Biochemical oxygen demand	SVOC (Semi-Volatile Organic Compounds)
Temperature	Ortho-phosphate
pH (field)	Total phosphorous
Volatile organic acids	Total Kjeldahl nitrogen
	Total dissolved solids
	Sulfate
	Chloride
	Potassium
	Conductance (laboratory and field analyses)
	RCRA hazardous metals
	Ammonia nitrogen
	Nitrate nitrogen
	Nitrite nitrogen
	Head on liner
	Leachate production

Table 3-5. Critical and Non-critical Measurements for Municipal Solid Waste

CRITICAL	NON-CRITICAL
Waste temperature	Oxidation-reduction potential (ORP)
Waste settlement (GPS)	Cellulose:lignin ratio
Organic solids	Appearance of waste (e.g., color, texture, type)
Moisture content	
pH	
Biochemical methane potential (BMP)	

Table 3-6. Critical and Non-critical Measurements for Gas

CRITICAL	NON-CRITICAL
Methane, <i>field, lab (Summa)</i>	Surface emission monitoring
Carbon dioxide, <i>field, lab (Summa)</i>	Non-methane organic carbon
Oxygen, <i>field, lab (Summa)</i>	Hazardous air pollutants
Gas volume	

3.3 Data Evaluation Given the difference in age between the treatment and control landfill cells and the small number of cells available for the investigation, there is a concern about the comparability and the validity of drawing inferences from such a small number of experimental units. Due to these concerns, more robust statistical methods will be employed when appropriate. Typically non-parametric methods are more robust than parametric ones, hence they are recommended here. While both parametric and non-parametric statistical methods require the data to be comparable and meet specific assumptions, most non-parametric methods require fewer assumptions to provide probabilistic, quantitative statements about the conditions being tested.

Comparability of treatment and control data (i.e., comparability among landfill cells) will be carefully examined before performing any statistical analyses. The time lag between treatment and control for this project could introduce several factors that may affect comparability that cannot be controlled in the design; e.g., weather and the type of waste contained in each cell. There may be other issues that cannot necessarily be identified until the data are examined. If the treatment and control data resulting from this project are determined to be incomparable, the recommendations and conclusions will focus on the weight of evidence provided by exploratory data analysis to evaluate the effectiveness of the treatment. These techniques include calculation of summary statistics and investigation of the data using pictures and graphs. Regardless of the method of statistical analysis, graphs and pictures of the data will be used to increase understanding of treatment and control behaviors.

Summary statistics, including number of samples, number of detects, minimums, means, medians, maximums, and standard deviations of detected values will be presented. Because time is a key variable in this project, the time frame over which summary statistics are provided becomes important. For an overall difference between treatment and control, the data from the start to end of the project will be grouped into summary statistics. For differences over time, the

summary statistics will be calculated from the data corresponding to the time frame of interest; for example, quarterly, yearly, or seasonally.

In all cases, the data will be plotted. Graphical data-analysis tools that will be implemented include time plots, bubble plots, box plots, 3D color plots, and isopleth maps. These types of plots will provide an understanding of possible time dependencies and the potential differences between treatments and the control. Time plots show time on the x-axis and the dependent variable on the y-axis. Box plots give an indication of the frequency distribution of the data and help validate assumptions of statistical tests that are under consideration. Bubble plots provide an indication of the spatial distribution of results; data are plotted on maps as bubbles, with the size of the bubble proportional to the concentration. These will be used to make, between and within, treatment and control comparisons over time. Examples these types of plots are presented in Appendix I.

Assuming the data from treatment and control are comparable, there are several statistical analyses that will be performed; these are discussed in the following sections. Part of the data assessment will include verifying the assumptions of the statistical analyses to ascertain whether conclusions based on the analyses are valid. For most of the time series analyses, the recommended test is the non-parametric Mann-Kendall test. The Mann-Kendall test for trend uses the relationship between time-adjacent results to determine whether there is sufficient evidence to detect an increasing or decreasing trend. To perform the Mann-Kendall test, data are ordered by sample date and the sign (positive or negative) of all sequential differences is recorded. The test statistic is the sum of the number of positives minus the number of negatives. If the sum is close to zero, then no trend is assumed. If the sum is large and positive (negative) then a positive (negative) trend can be assumed. Note that the test statistic is a function of the relationship between values rather than the values themselves, as is the case with most non-parametric tests (Hollander and Wolfe, 1973). An example of the Mann-Kendall test is presented in Appendix I.

3.3.1 Leachate As stated above, leachate will be collected from each of the cells in the study. The design of the landfill units (paired cells) is such that, with the exception of Unit 5, each cell is separated from the surrounding cells. Regarding Unit 5, sample locations for subunits 5 North and 5 South are separated by ca. 1,000 feet of waste; a distance judged to be adequate for separation by EPA's Office of Research and Development landfill expert, Dave Carson. The median of the two treatment cell observations from each sampling event will be calculated, resulting in a single time series for each treatment and control. These time series will be used to determine trends, or lack thereof, for those characteristics and analytes measured in the leachate. Because these data will be collected over a period of months, there is the potential for seasonal variations in the time series, at least with regard to moisture. And because the Mann-Kendall test for trend evaluates monotonic trends (overall increasing or decreasing), seasonal variations must be considered. There are two possible ways to account for seasonal variation; one is to perform a Mann-Kendall test on the differences between treatment and control series, another is to parametrically model each time series individually and perform a Mann-Kendall test on the residuals from each.

If the data from treatment and control cells can be paired (i.e., they are comparable), their differences can be subjected to a Mann-Kendall test. The assumption is that the treatment and control will follow the same trend for a given measure, but the time period over which the trend occurs may be different, with the trend in the treatment cell being accelerated over time compared with the control cell. In this case, the differences between treatment and control will get larger over time, hence the differences will show an increasing trend, even if seasonal fluctuations are present. If this approach is to be taken, the treatment and control observations that are combined (through differences) will be as comparable as possible. For instance, if the treatment data are collected monthly over time starting in January, then the control samples will be paired over time accordingly. In other words, the treatment data will be collected monthly and the differences will be calculated on the same months.

Although research has indicated that seasonal variability in stabilization is likely (Saint-Fort 2002), both control and treatment data can be parametrically modeled as a time series to account for seasonal differences by a Mann-Kendall test on the residuals. The residuals are the differences between the modeled results and the actual results. Diggle (1990) provides a good basic discussion of parametric time series modeling. A parametric time series model will identify the autocorrelation (time dependence) present in a given series. This could provide information about whether the treatment is accelerated over the control as well as account for seasonal variations. One element of parametric time series modeling is to identify the lag, otherwise known as the time period between correlated observations.

Parametric time series modeling is capable of identifying many different lags in a time series. For this project, a seasonal lag might be expected, but also a lag due to the stabilization process itself. Depending upon the data, each of these lags may be identified by the model. If the stabilization process lag for the treatment series is shorter than the lag for the control series, there is evidence that the treatment is effective. If the process lag is not evident in the model, but the seasonal lag is, the residuals can be tested separately to find the process lag, if there is one. These residuals should have no seasonal variation, and, if an underlying trend is present, it will be evident in the residuals. The results of the Mann-Kendall tests will then be used, along with time plots, to compare the treatment and control trends. For instance, if the Mann-Kendall test indicates that both residual series show an increasing trend, time plots will confirm that the treatment trend is accelerated over the control trend.

3.3.2 Gases Gas sampling for critical measurements (CO₂, O₂ and CH₄) will be performed weekly. Non-critical measures (NMOC and HAPs) and methane surface emissions monitoring will be performed quarterly (Table 3-3). Similar to leachate, gas sampling will occur at one point per cell where the cell's gas extraction wells come to the collection point. The extraction wells will be located systematically, approximately equidistant from one-another. The number and location will be chosen such that the variation within a cell is adequately characterized.

Exploratory data analysis, time series modeling, and trend testing will be performed on a location or a cell basis. Spatial patterns in the data will be considered before combining the data within a cell to compare with another cell. If the data are adequate, spatial analyses, such as block kriging or linear interpolation, will be used to compare patterns of gas generation in the treatment and

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control cells. Isopleths of gas volumes over time will be created for each cell and their magnitudes and shapes compared visually. This will give an indication of treatment effectiveness when the plots are placed side-by-side for the same time frames. If the spatial patterns of gas volume remain homogeneous over time, the data from a given time frame will be combined into a median or mean for treatment control comparisons.

3.3.3 MSW (Municipal Solid Waste) Solid waste samples will be collected annually through systematic boring locations. Dividing the cell into six sections, dividing a section in 3x3 square meter grids and randomly choosing a square within a grid will identify the boring location within a section. The equivalent boring location will be used for sampling in the remaining sections. This sampling plan will exclude sampling on the edges of the cell. In addition, if drilling cannot be initiated (e.g., known asbestos deposit underneath) or completed (e.g., impenetrable object encountered) in a potential location, a randomly selected square adjacent to the original location will be selected (only for that section where drilling was incomplete). Along with the two dimensional analyses outlined for leachate and gas, three-dimensional analyses will be done for municipal solid waste. That is, because borings will be collected and depth samples collected, the trend and spatial analyses will incorporate depth. If, for some reason, the treatment is more effective at one depth than at others, incorporating depth into the MSW data assessment might identify it. Because the number of locations for collecting MSW is much less than for gases, spatial patterns and/or time trends in the MSW (e.g., waste density) will be more difficult to identify, but it may be possible. For example, typical p-value tables for the Mann-Kendall test require at least 4 samples, so the MSW data will meet the minimum requirements of the test, as long as no data are rejected or lost.

Settlement of the fill will be monitored quarterly through GPS measurements of elevation as a indication of stability. The numerous GPS sample points will provide a data set with which to evaluate waste settlement. Specific details on the employed technique, global positioning (GPS) surveying, are provided in Section 4.4.3.

4.0 SAMPLING PROCEDURES

4.1 General Specific sampling procedures have been developed by the EPA and vary with the sample matrices and specific analyses. The types of containers, methods of preservation and holding times are identified in Table 4-1. These meet specifications for EPA approved methodology, and are appropriate for the parameter and matrix of interest. EPA documents specify techniques for field sampling and this QAPP lists methods to be used for this demonstration. Specifics have been included for critical measurements including type of sample, sampling location, field sample preparation techniques, and sample handling requirements. The EPA provides guidelines for sample collection as part of the Resource Conservation and Recovery Act (RCRA) regulations. WMI personnel will refer to the procedures found in SW 846 for all sampling protocols used as part of this demonstration. Equipment used for field sampling is calibrated and maintained according to manufacturer's guidelines. Solid-waste probes (Temperature and ORP) will be employed with enough redundancy to compensate for potential failure in the field.

For example, A pH meter with automatic temperature compensation capable of measuring pH at the demonstration site to ± 0.1 pH units will be used. The pH probe will be calibrated each time the instrument is set up using two buffer solutions that bracket the expected pH. Precision will be determined by analyzing a duplicate during each sampling event. The results must agree within ± 0.1 pH units or the instrument will be recalibrated and the results reanalyzed. Accuracy will be determined by measuring a third buffer solution as if it were a sample. The results must agree within ± 0.1 pH units or the instrument will be recalibrated. A standard Cole-Parmer Thermocouple will be used for field temperature measurements. Because standard thermocouples are themselves considered the industry standard, no calibration procedures will be required. In addition, Standard Methods for the Examination Water and Wastewater and individual analyte methods provide valuable information for ensuring that samples are properly collected, stored and preserved. Laboratories used during the course of this study for sample analyses will be required to follow these guidelines.

The method of shipping depends on the sample type and the common carrier available. It is anticipated that all samples will arrive within 24 hours of collection. An overnight shipping company will be used for this purpose. Samples requiring cooling for purposes of preservation will be packaged in coolers and maintained at 4°C using commercially available crushed ice. Ice will be packaged in large Ziploc baggies to prevent leakage onto sample containers. Shipping samples by overnight carrier will help to ensure samples arrive at the laboratory at 4 °C. In addition, overnight delivery will be critical for nitrate, nitrite, BOD and ortho-phosphate measurements that need to be measured within 48 hours. The laboratory will be contacted prior to the day of shipment to ensure sample analysis can be expedited upon arrival. The laboratory will record the shipment temperature (of a temperature blank) upon arrival and significant variances in temperature (i.e. greater than 4 °C) will be immediately reported to the WMI project Co-Principal Investigator responsible for field activities (i.e., Roger Green).

Under the supervision of Roger Green or Douglas Goldsmith, all project personnel for field activities will complete a sample collection narrative form. The team member responsible for

the sampling project completes the narrative and it travels with the Chain of Custody. It is a record of all activities carried out by the sampling team. The sample collection information is also recorded on an analytical data sheet for field-testing parameters such as pH, specific conductance, gas surveys etc. To maintain sample integrity and to assure the validity of results, well-documented Chain of Custody (COC) records are essential (Section 4.7.3).

4.2 Site Specific Factors Affecting Sampling The only two factors that have impacted the sampling of a landfill in the past have been inclement weather and equipment failure. If these situations should occur, alternate sampling periods will be specified by the WMI Project Manager and Co-Principal Investigators and the EPA Project Co-leaders in order to accommodate the collection of critical information.

4.3 Site Preparation Required for Sampling Activities Each sampling location will be appropriately marked with stakes and identification codes. The WMI Project Manager, Gary Hater, will conduct a review of the sampling points before each sampling event for leachate, MSW or gases.

4.4 Sampling/Monitoring Procedures

4.4.1 Leachate Samples will be taken at the sump areas for Units 5N and 5S, 7.3A and 7.3B, 7.4A and 7.4B. Samples are obtained at regular time intervals at one sampling location. Leachate samples will be collected directly from the tap on the riser pipe. Switching the riser pump from automatic mode to hand mode (essentially turning the pump off) prior to sampling has been shown in subsequent sampling events to be an effective procedure for obtaining an adequate volume of leachate sample. Leachate sample bottles will be collected in the following sequence: COD, BOD, volatile organic acids, pH, temperature, VOCs, SVOCs, TKN, ammonia-N, nitrate-N, nitrite-N, total metals (including potassium), ortho phosphate, total phosphate, chloride, sulfate and TDS. This sequence is also specified on the attached Leachate Sampling Information Form. To obtain a representative sample, effluent will be purged prior to collecting the actual sample. The purge volume will also be recorded on the Leachate Sampling Information Form.

4.4.2 Gases Gas monitoring will be done at the installed gas monitoring point within a cell to monitor activity within the landfill bioreactors and control areas. Information recorded for gas sampling will be logged on the attached Gas Sampling Information Form. Gas analyses will be performed for methane, carbon dioxide, and oxygen using a GEM 2000 (Appendix C). This instrument is a portable field gas analyzer and uses a self-compensating infrared detector. Gas volume measurements will be made by electronically logging three consecutive measurements (one measurement per minute) of gas quality (methane, carbon dioxide, oxygen, and balance gas) and flow (differential pressure, static pressure, gas temperature, and flow rate) to the GEM 2000 for each sample point. The mean value for each of these measurements will be recorded as the value for each parameter of interest.

Surface emissions monitoring will also be performed for methane using the field instrument CEC-Landtec SEM-500. This is a hand held portable flame ionization detector used to monitor

surface emissions at landfills. Both instruments will be calibrated prior to use per manufacturer specifications. In addition, for the landfill gas analyses routine field checks will be made using each of the three critical gases listed. Certified gas mixtures will be obtained from a reputable distributor (e.g. Scott Specialty Gases). This will include two concentrations that bracket the expected measured concentration and a “zero” gas (e.g. nitrogen). The instrument reading will be checked against the calibration gases twice daily on the day of sampling. Concentrations will be checked prior to instrument use and at the end of the day after field measurements are completed. Concentration readings for carbon dioxide and methane are to be within 15% of the actual concentration or sample duplicate; the tolerance for oxygen is $\pm 30\%$ (Table 6-1-3). Zero gases should register no greater than 5% of the span of the instrument. Atmospheric oxygen (20.9%) can be used as one of the oxygen reference gases. See below for specific information regarding field instrument specifications.

4.4.2.1 Field Analyses (weekly monitoring) Landfill gas will be sampled and analyzed to determine the composition of the gas. The majority of the samples and analyses performed will be made for the determination of methane, carbon dioxide, and oxygen concentration using a portable landfill gas analyzer (GEM 2000). After calibration according to the manufacturer’s instructions, the instrument is connected to a gas sampling port using flexible plastic tubing. Gas is drawn into the instrument by an internal pump and analyzed. Results are date and time stamped and datalogged by the instrument. Gas standards for CH₄, CO₂ and O₂ will be analyzed twice daily on the day of sampling (Table 6-1-3) to evaluate accuracy objectives (Table 6-9). One sample duplicate will be collected in a Tedlar bag on each day of sampling and the sample location will be rotated through the various units under study. The sample duplicate will be used to assess precision objectives (Table 6-1-3). Gas volume measurements will be made by electronically logging three consecutive measurements of gas quality (methane, carbon dioxide, oxygen, and balance gas) and flow (differential pressure, static pressure, gas temperature, and flow rate) to the GEM 2000 for each sample point. The mean value for each of these measurements will be recorded as the value for each parameter of interest.

4.4.2.2 Laboratory Analyses (quarterly monitoring) Landfill gas samples will also be collected for laboratory analysis of methane, carbon dioxide, and oxygen by EPA Method 3, non-methane organic compounds (NMOCs), by EPA Method 25C, and volatile organic hazardous air pollutants (HAPs; Appendix J) by Compendium Method TO-14. These samples will be collected in 6-liter SUMMA[®] passivated stainless steel canisters at the gas monitoring point.

4.4.2.3 SURFACE EMISSIONS MONITORING (TWICE QUARTERLY) SURFACE EMISSIONS MONITORING WILL BE PERFORMED IN ACCORDANCE WITH THE REQUIREMENTS SPECIFIED BY THE NEW SOURCE PERFORMANCE STANDARDS (NSPS) AND EMISSION GUIDELINES (EG) FOR MUNICIPAL SOLID WASTE LANDFILLS IN 40 CFR 60.755. METHANE CONCENTRATIONS ARE MEASURED WITHIN 5 TO 10 CM (2 TO 4 IN) OF THE LANDFILL SURFACE USING A CEC-LANDTEC SEM-500. METHANE CONCENTRATIONS ARE MEASURED FOLLOWING THE PROCEDURES IN EPA METHOD 21, EXCEPT THAT "METHANE" REPLACES ALL REFERENCES TO "VOLATILE ORGANIC COMPOUNDS" (VOC) AND THE CALIBRATION GAS IS 500 PPM METHANE IN AIR [§

60.755(D)]. METHANE SURFACE CONCENTRATIONS ARE MONITORED AROUND THE PERIMETER OF THE COLLECTION AREA AND ALONG A PATTERN THAT TRAVERSES THE LANDFILL AT 30-METER INTERVALS AND WHERE VISUAL OBSERVATIONS INDICATE ELEVATED CONCENTRATIONS OF LANDFILL GAS (E.G., DISTRESSED VEGETATION, CRACKS OR SEEPS IN THE COVER).

4.4.3 MSW (Municipal Solid Waste) Municipal solid waste sampling procedures will essentially follow those traditionally used in the industry. A drill rig equipped with a 3' bucket auger will be used. As indicated in Section 3.3.3, six locations on the surface will be sampled. Each location is sampled with the bucket auger in 10' vertical sections with one representative sample collected for each section. The initial 10 feet of material is generally discarded as it predominantly contains soil and not MSW. As the boring advances, each 10-foot sample is extracted from the auger and the appearance of the waste is observed and recorded. It is anticipated that at least five 10' increments will be collected from each of the six sampling locations. As such, a minimum of 30 solid-waste samples will be collected for each cell on an annual basis (Table 3-2).

The 10-foot waste sample is sealed in a plastic bag and placed in cooler for shipment to the laboratory. This includes samples for organic solids, pH, moisture content, biochemical methane potential, and cellulose/lignin ratio at the frequency designated in Table 3-2.

Temperature and ORP of the in-place MSW will be monitored by type T-thermocouple probes connected to a PC-driven data collection system. The data communications/gathering system that the probes are connected to currently record the temperature or ORP reading for each probe once every 30 minutes. These data will be used to construct a control chart for each probe. Probes returning erratic temperature readings, based on the historic temperature control charts will be investigated. For most probes in Unit 5, this will involve removal, inspection of connections and the probe and if necessary replacement. The probes to be installed in 7.4 A and B will be permanent and not replaceable. Erratic results from these probes will be flagged.

Global positioning (GPS) surveying with the Trimble model 4800 will be performed on sampling points within a cell as follows: 1) Every sampling event will be initialized from a known point and will agree to ± 5 cm for the horizontal and vertical coordinates of the known point — if sampling within a cell is interrupted, the system will be reinitialized from the known point before sampling resumes; 2) sampling will not be initiated if the root mean square reading from the system is less than 15; and, 3) the positional dilution of precision (a measure of the relative dispersion of satellites in the sky) reading will be six or less before the system is initialized. In addition, one of every 20 points measured by GPS will be randomly selected and resampled. The results will be compared to Table 6-1-4. If these conditions are met, the positional accuracy of the GPS readings will be sufficient to meet the analytical needs of this QAPP.

4.4.4 Sampling Strategy Several parameters were considered when developing a sampling strategy to represent the chemical, biological and physical status of a landfill in the best way possible. Because each cell's leachate drains to a central sump, samples collected at sumps should be representative of the entire cell. Systematic locations for the gas extraction wells and

soil boring locations were chosen to maximize the coverage within the zone of maximum vertical resolution (i.e., away from the sides of the cell). Matrices will be sampled according to the schedule provided in Tables 3-1, 3-2 and 3-3 to provide a “snapshot” of the historical contents of the landfill. The goal is to effectively choose enough points on the landfill to get a complete picture upon combining the information from each snapshot.

4.5 Laboratory Responsibilities Outer Loop personnel will be conducting leachate and gas sampling under the supervision of Roger Green. Subcontracted laboratories will be conducting leachate, gas and MSW analyses. Severn Trent Laboratories will be responsible for leachate and gas and North Carolina State University will conduct MSW testing (Table 5-1).

4.6 Field and In-Situ Equipment Temperature and ORP of the in-place MSW will be monitored by type T thermocouple (see above) wire connected to a Cole-Parmer thermocouple panel meter on the surface. One temperature and ORP reading will be made on a daily basis per cell. A submersible in-line electrode fitted in a PVC casing for protection will measure the temperature and pH of the leachate. The signal will be boosted by a preamplifier, due to the amount of cable required, to a pH controller box with LED readout on the landfill surface. Calibrations will be performed per manufacturer specifications. The pH calibrations will be performed using standardized pH solutions of 7 and one other solution to bracket the pH of the measured leachate. An in-place pressure transducer measures the head on the landfill liner and leachate production is quantified with a factory-calibrated totalizing flow meter (1 per cell).

A factory-calibrated orifice plate (certified prior to project initiation) is used to measure gas production. All other field gas measurements (methane, carbon dioxide, and oxygen) will be measured using the GEM 2000. Calibration and QC specifications are noted above. Waste settlement is measured using a Trimble 4800 GPS system through quarterly monitoring. Measurements taken on a quarterly basis will be compared to pre-demonstration measurements for determination of waste settlement over time. The system has a vertical resolution of ± 2 cm when employed in a kinematic (walking) survey (versus a stationary survey vertical resolution of ± 5 mm). Positioning accuracy is determined by methods outlined in Section 4.4.3.

4.7 Sample Management The following are procedures for identifying samples and ensuring that data can be correctly identified at a later date.

4.7.1 Sample Identification

4.7.1.1 Samples collected for laboratory analysis are identified with standard labels attached to the sample containers. The following information will be included on the sample labels (using waterproof ink), in the order indicated: unit number, cell number, cell letter (if applicable), sample matrix/sample type, sampling location number (within this cell), sample depth or depth interval in feet below ground surface elevation (if applicable). The label also will list the date and time the sample was collected. The sample should be identified using the following format.

[#] [#] [X] [X] [#] [#] [#] [#] — [#] [#]

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Unit No.	Cell No.	Cell Letter	Sample Matrix/ Type	Sample Location No.	Sample Depth or Depth Interval
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Valid unit numbers are 5 or 7. Valid cell numbers are 1,2,3, or 4. Valid cell letters are A or B. The sample matrix or sample type will be indicated using a single letter according to the following table.

Sample Matrix/Type	Sample Matrix/Type Code
Leachate	L
Gas	G
Solid waste	W
Waste Temperature	T
Waste ORP	O
Surface Emissions	E

For example a solid waste sample collected from the AALB in cell 7.4A at sampling location 1 from a depth interval of 10 to 20 feet below ground surface would be identified as 74A W01 10-20. Notice that a space is left between the cell letter and the sample matrix/type code and between the sample location number and the sample depth.

[7]	[4]	[A]	[W]	[0]	[1]	[1]	[0]	—	[2]	[0]
Unit No.	Cell No.	Cell Letter	Sample Matrix/ Type	Sample Location No.		Sample Depth or Depth Interval				

Note that not all combinations of unit numbers, cell numbers, and cell letters are valid. For the FLB the combinations 51A, 51B, 52A, or 52B will be used; for the AALB the combinations 74A and 74B will be used; and for the Control the combinations used will be 73A, and 73B. Gas volume and quality measurements for the FLB are collected from two gas metering stations. One of these stations represents cells 5.1A and 5.1B, while the other represents cells 5.2A and 5.2B. Therefore, the identification for these samples will not include the cell letter. For example samples collected from the metering station representing cells 5.1A and 5.1B will be identified as 51 G01.

4.7.2 Containerization, Preservation and Holding Times

Table 4-1. Proper containers, preservatives and holding times for landfill bioreactor studies

Parameter	Sample volume & container	Preservation	Max. Holding Time
Inorganic Tests			
Ammonia-nitrogen	500 ml, P,G ¹	Cool 4° C, H ₂ SO ₄ to pH<2	28 days
BOD	1000 ml, P,G	Cool 4° C	48 hours
COD	500 ml, P,G ¹	Cool 4° C, H ₂ SO ₄ to pH<2	28 days
Chloride	500 ml, P,G	None required	28 days
Potassium	500 ml, P,G	Field acidified to pH<2 with	28 days

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		HNO ₃	
Kjeldahl Nitrogen	1000 ml, P,G ¹	Cool 4° C, H ₂ SO ₄ to pH<2	28 days
RCRA Metals	1000 ml, P,G ¹	Field acidified to pH<2 with HNO ₃	6 months (Hg = 28 days)
Nitrate-nitrogen	1000 ml, P,G	Cool 4° C	48 hours
Nitrite-nitrogen	1000 ml, P,G	Cool 4° C	48 hours
ortho-phosphate	500 ml, P,G	Cool 4° C, filter in lab if necessary	48 hours
Total phosphorous	500 ml, P,G ¹	Cool 4° C, H ₂ SO ₄ to pH<2	28 days
Total Dissolved Solids	500 ml, P,G	Cool 4° C	7 days
Temperature (leachate)	P,G	None required	Analyze Immediately
pH (leachate)	P,G	None required	Analyze Immediately
pH (waste)	1000 ml wide-mouth, P,G	Cool 4° C	7 days
Moisture (MSW)	1000 ml wide-mouth, P,G	Cool 4° C	28 days
Density (MSW)	Volumetric box	None required	Field measurement
Sulfate	50 ml, T,P,G	Cool 4° C	28 days
Specific Conductance	500 ml, P,G	Cool 4° C	28 days
Organic Tests			
Organic solids	Double-wrapped plastic garbage bag ²	Cool 4° C	21 Days
Cellulose:lignin	Double-wrapped plastic garbage bag ²	Cool 4° C	28 Days
BMP	Double-wrapped plastic garbage bag ²	Cool 4° C	21 Days
Volatile Organic Acids	8 oz. amber glass, Teflon-lined septa	Cool 4° C	10 days
Volatile Organic Compounds	3x40 ml glass, Teflon-lined septa	Cool 4° C, no headspace	7 days
Semi-volatile Organic Compounds	2x1 L Amber glass, Teflon-lined septa	Cool 4° C	Extract - 7 days Analyze - 40 days
CH ₄ , CO ₂ , O ₂	6 liters, S	None required	7 days

¹ Sample bottles will be of sufficient volume to prevent sample loss due to effervescence upon acidification

² wrapped samples placed in polyethylene trays with lids and these filled trays are then placed in a (un-cooled) plastic bin

P - Plastic

Sources: SW 846 Methods

G - Glass

40 CFR 136

T - Teflon

Standard Methods for the Examination of Water and Wastewater

S - Summa canister

4.7.3 Sample Handling and Shipment The WMI senior scientist in charge of field activities will be responsible for ensuring that appropriate chain-of-custody procedures are followed for each sample from the time it is collected until it is analyzed in the laboratory. Samples will be retained at all times in the custody of the sampler, field manager (if a different individual), or designated field sample custodian, until shipment. Transfer of custody between field personnel will be documented on the custody form. The field manager will ship collected leachate and gas samples to Severn Trent Laboratories and MSW samples to North Carolina State, Raleigh, NC, laboratories at the end of each sampling day. The following information will be required on the chain-of custody form:

Project No.: Enter the complete project number
Project Name: WMI/EPA Landfill Bioreactor Project
Sample Number: Enter the sample ID number
Date: Enter the date of sample collection
Time: Enter the time of sample collection

Sample

Description/Type: Enter the sampling location and matrix type
Analysis Required: List the parameters to be analyzed and QC requirements (MS/MSD)
Preservation: Provide description of preservation

Each container should be labeled at the time it is filled with the sample description, number, date, time, and sampler's initials. Waterproof ink or marker will be used to ensure that the information can be read after shipping. In addition, each sample label will be wrapped with clear packaging tape at the time of collection in order to prevent loss of sample information. When sampling is complete, the sampler should retain or make a copy of the completed COC. The original COC should be protected by sealing in a Ziploc baggie and placed in the cooler with samples for transport. Field personnel will verify this documentation for accuracy before placing it in the cooler with samples. When all line items are completed and before shipping, the field manager will sign and date the chain-of-custody form, list the time, and confirm that all descriptive information contained on the form is complete.

All samples will be packaged and labeled for shipment in compliance with current regulations. Laboratory and WM specifications for sample packaging and shipment will be followed for each type of sample and for each laboratory. For example, ice chests used to ship aqueous samples will be lined with two plastic bags; twisting the tip and securely taping the bag closed to prevent leaks will seal the plastic bags around the aqueous samples. Styrofoam, bubble wrap, or other packing materials will be used to absorb shock for all breakable sample containers. Samplers will place ample absorbent material in coolers for the case of possible sample jar breakage during shipment. Chain-of-custody record forms and any other shipping and sample documentation will accompany the shipment. These documents will be enclosed in a waterproof plastic bag and taped to the underside of the cooler lid. Each ice chest prepared for shipment will be securely taped shut. Reinforced or other suitable tape (such as duct tape) will be used and wrapped at least twice around the ice chest near each end where the hinges are located. Two custody seals will be placed on the cooler. Sample shipping containers will be marked in accordance with U.S. regulations for airborne shipping. When selecting means of shipping samples, field personnel will ensure that the method chosen will not cause the sample to exceed allowable holding times. When commercial common carriers are used to ship samples, all samples will be shipped for overnight delivery.

In accordance with laboratory regulatory requirements and the standard written procedures of the laboratory, the laboratory sample custodian or designated alternate will receive and assume custody of samples until the samples have been properly logged in to the laboratory and stored in a secured area. When a sample shipment is received at the laboratory, the shipping container will be inspected for warning labels and security breaches before it is opened. The sample custodian will open the container and carefully check the contents for evidence of breakage or leaking. Preservation requirements regarding pH and temperature will be verified, as appropriate for aqueous samples at the time samples are received. Deviations will be reported to the WMI senior scientist in charge of field collection immediately and will be noted in the case narrative report based on chain-of-custody records.

The contents of the container will be inspected for chain-of-custody record forms and other information or instructions. The sample custodian will record the date and time on the chain-of-custody record form. The sample custodian will verify that all information on the sample container labels is correct and correlates with the information on the chain-of-custody record, and will sign the chain-of-custody record. The chain-of-custody record form will be retained in the project file and a copy returned to the WMI senior scientist in charge of field activities to verify receipt. Any discrepancy between the samples and the chain-of-custody information, any broken or leaking sample bottles or any other abnormal situation will be reported to the WMI contract laboratory quality coordinator. The WMI project manager will be informed of any problem, and corrective action will be discussed and implemented. The problem and its resolution will be documented, initialed and dated by the sample custodian.

In accordance with regulatory laboratory certification requirements and the standard written procedures of the laboratory, samples will be handled, stored and processed in the required way and so as to minimize errors and degradation of sample integrity. Each shipment of samples received at each laboratory will be assigned a work order number. Each sample in the shipment will be given a unique laboratory sample number that includes the work order number and an identifying code. A laboratory sample label specifying the unique identifier will be attached to each container. The work order will specify the samples to be analyzed, the analysis required, the project-required QC, and any other necessary information. Bench sheets, initiated at the first point of sample preparation, are to accompany the samples throughout the analytical sequence.

4.8 Field Documentation All handwritten documentation must be legible and completed in permanent waterproof ink. Corrections must be marked with single line, dated, and initialed. All documentation including voided entries must be maintained within project files.

4.8.1 Project Logbooks Field personnel will record all information pertinent to the sampling and measurement program in a consecutively numbered field logbook. The information will be entered into the field logbook at the time of sampling. At a minimum, the logbook will contain the following.

Documentation of Calibration of Field Equipment

- Date and time of calibration
- Calibration data
- Instrument identification, including manufacturer and model

Background Information

- Date and time of the sampling activities
- Personnel on site
- Weather conditions
- Purpose of sampling

Chronology of Sampling

- Description of sampling points and sampling methodology
- Number and volume of samples collected
- Date and time of collection
- Sample identification number

- Field observations about any problems encountered and deviation from the QAPP
- Sample Distribution
- Sample distribution and method of transport (name of laboratory where samples were sent, overnight courier service used, air bill number, and other information)
 - Signature of sampler or field sample custodian

Each page will be dated and signed by the person making the entries. Logbooks are accountable field documents and serve as a chronological representation of the sampling and measurement program. Sufficient detail will be included in the logbook to provide a summary of sampling and measurement activities. Observations or measurements taken in the area where contamination of the field notebook may occur may be recorded in a separate bound and numbered logbook before being transferred to the project notebook. The original records will be retained, and the delayed entry will be noted as such. Field notebooks are intended to provide sufficient data and observations to enable participants to reconstruct events that occur during project field activities.

4.8.2 Corrections to Documentation All original data recorded in the field notebooks and on sample identification tags, chain-of-custody records, and receipt-for-sample forms will be written in waterproof ink. These accountable, serialized documents are not to be destroyed or thrown away, even if they are illegible or contain inaccuracies that require a replacement document. If an error is made on an accountable document assigned to one person, that individual may make corrections simply by crossing out the error and entering the correct information. The erroneous information should not be obliterated. The person who made the entry should correct any error discovered on an accountable document and provide a brief explanation for the correction. All corrections must be initialed and dated.

5.0 TESTING AND MEASUREMENT PROTOCOLS

5.1 Method References

Table 5-1. Method References

Monitoring Parameter	Analyst	Method (Source)
<i>Leachate</i>		
Head on Liner	Waste Management	Pressure transducer
Leachate Production	Waste Management	Totalizing Flow Meter (1 meter per cell)
Temperature	Waste Management	Cole-Parmer Thermocouple, field electrode
Leachate pH, field	Waste Management	Field electrode (C/A)
Leachate pH, laboratory	Severn Trent	US EPA 9045C
Chemical Oxygen Demand	Severn Trent	410.4 (C)
Biochemical Oxygen Demand	Severn Trent	405.1 (C)
Conductance, field	Waste Management	Field electrode (C/A)
Ammonia-nitrogen (NH ₃ -N)	Severn Trent	350.1 (C)
Nitrate-nitrogen (NO ₃ -N)	Severn Trent	353.2 (C)
Nitrite-nitrogen (NO ₂ -N)	Severn Trent	353.2 (C)
Volatile organic acids	Microbial Insights	Microbial Insights SOP
VOC	Severn Trent	8260B (B)
SVOC	Severn Trent	8270C (B)
ortho P / Total P	Severn Trent	365.2 (C)
Total Kjeldahl Nitrogen	Severn Trent	351.2 (C)
Total dissolved solids	Severn Trent	160.1 (C)
Sulfate	Severn Trent	300.0 (A)
Chloride	Severn Trent	300.0 (A)
Potassium	Severn Trent	6010 (B) (prepared according to 3005)
RCRA hazardous metals*	Severn Trent	6010/7470 (B) (prepared according to 3005)
<i>MSW</i>		
Oxidation Reduction Potential	Waste Management	Field ORP electrode (C/A)
Waste temperature	Waste Management	Cole Parmer Thermocouple
Waste settlement	Waste Management	GPS survey (Trimble model 4800)
Waste pH (field)	Waste Management	Field electrode (C/A) (Appendix G)
Cellulose:lignin ratio	North Carolina State Univ.	ASTM E-1758-95/Barlaz (R&D Method)
Organic solids	North Carolina State Univ.	Barlaz R&D Method (Appendix D)
Biochemical Methane Potential (BMP)	North Carolina State Univ.	Barlaz R&D Method (Appendix E)
Moisture content	North Carolina State Univ.	Barlaz R&D Method (Appendix F)
Density	North Carolina State Univ.	Borehole Sampling (field)
<i>Gas</i>		
Landfill gas flow/production	Waste Management	Orifice plate, Earth Tech
CH ₄ , CO ₂ , O ₂	Waste Management	GEM 2000. See Section 4.4.2, Table 6-9 and Appendix C
CH ₄ , CO ₂ , O ₂ , SUMMA Canister	Severn Trent	3 C
Non Methane Organic Carbon (NMOC) (SUMMA Canister)	Severn Trent	25C (C)

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Hazardous Air Pollutants (HAPs; Appendix J) (SUMMA Canister)	Severn Trent	TO-14 (Appendix J)
Surface emission monitoring (SEM)	Waste Management	NSPS/FID modified method 21

*RCRA hazardous metals include As, Ba, Cd, Cr, Pb, Hg, Se, Ag and potassium. Mercury prepared and analyzed according to 7470.

5.2 Procedures For Analytical Equipment and Test Methods This section references calibration procedures, frequencies of calibration and required detection limits for each sampling and analytical system to be used. Calibration requirements for standard, EPA-approved methods are described in the reference methods.

- A. EPA, 1988, Methods for the Chemical Analysis of Water and Wastes (MCAWW). Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, Revised March 1988. EPA-600/4-79-020
- B. EPA, 1986. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Laboratory Manual, Volume 1A through 1C, and Field Manual, Volume 2. SW-846 Third Edition, Final (Promulgated) Update III, Office of Solid Waste, EPA Document Control No. 955-001-00000-1, December. [Note: For convenience, this reference is referred to as "SW-846" throughout this document.]
- C. Title 40 Code of Federal Regulations, Part 60 (Appendix A), Parts 136 and 29 CFR, and Parts 1910, 120, 1200 and 1450 as updated.
- D. Standard Methods for the Examination of Water and Wastewater, 19th Edition, 1996.
- E. EPA, 1996. Compendium of Methods for the Determination of Toxic Compounds in Ambient Air. EPA-625/R-96-010b.

6.0 QA/QC CONTROLS Reliable analytical measurements of environmental samples require continuous monitoring and evaluation of the analytical process involved, i.e. quality assurance. To ensure optimum generation of valid data, a scientifically sound and strictly followed quality control program must be incorporated into the sample collection and analytical program. Quality assurance objectives for this demonstration have been established based upon specific project requirements and are designed to ensure that data generated are of known and acceptable quality. The critical and non-critical measurements for leachate, MSW and gas have been previously listed in Tables 3-4, 3-5 and 3-6. This section of the QAPP summarizes the QA objectives for the critical measurements in terms of the data quality indicators: precision, accuracy, method detection limits, completeness, comparability and representativeness.

6.1 Definitions Accuracy and precision are two measures of the reliability of an analytical result. Accuracy is the degree with which the obtained result agrees with the true value (recovery). Accuracy may be described as the average of the results from repeated analysis of the same sample, compared to the actual amount of analyte in a specific sample. Precision is the degree of agreement among repeated tests of the same sample. By mathematical definition, precision is the percent difference of the results from reanalysis of a sample.

For this project, precision will be evaluated for parameters by the analysis of laboratory duplicates for laboratory measurements and field duplicates for parameters analyzed in the field. Precision between duplicates will be quantified as their relative percent difference (RPD). Field duplicates will not be collected for MSW samples. Accuracy will be assessed by the analysis of matrix spikes for laboratory samples. Field analyses will require comparison to a known standard (pH and gas analysis). For matrix spike analyses, a known quantity of the target analyte is added to an aliquot of a field sample and the percent recovery is determined. Accuracy is further assessed through the analysis of laboratory control samples (LCSs), also called spiked blanks, and through the use of second source standards, (performance evaluation samples). While the results for the LCSs will be evaluated and reported, the spiked sample results are those that will be used to assess QA objectives. Second-source standard analysis will be used to verify the accuracy of the calibration standards as well as tracking long-term accuracy over the duration of the project by assessing shifts in the bias.

Reporting detection limits (RDLs) are established by the lowest standard analyzed which meets the calibration curve linearity requirements. Method detection limits (MDLs) are established as per 40 CFR 136 Appendix B and are usually 3-5 times below the RDL. These limits will be adjusted as necessary based on contaminant levels, which may require higher dilutions. Completeness is the ratio of the total number of valid sample measurements generated compared to the number of measurements statistically determined to be necessary. Representativeness is ensured by a well-defined sampling strategy designed to collect samples, which exhibit average properties of the site. Field collection procedures ensure that the sample sent to the laboratory represents the entire interval of interest. Comparability is generally achieved by the use of standard EPA methods. Reporting the data in standard units of measure and adhering to the specified calibration procedures all contribute to comparability of the data.

6.2 Types of QC Samples Equipment Field Blank – All reusable sampling tools will be decontaminated by the appropriate washing/rinsing methods as given in SW 846 Chapter 9. Equipment blanks will be collected using DI water for all sampling equipment requiring decontamination.

Trip Blank - VOA-grade laboratory reagent water is placed in VOA vials by the laboratory and the vials are packaged and shipped with the sample VOA vials to the samplers; trip blanks remain with the sample bottles until use, then packaged and shipped with the samples for that day. A trip blank will be included in each cooler containing VOC samples

Sample Temperature - The bottles are kept at air temperature then placed in the cooler or shipping container at the same time as the refrigerant medium. At the laboratory the sample cooler and sample temperatures are checked with an infrared gun to assess whether the samples have been kept at a low enough temperature during shipment. Samples with temperatures above 4°C are flagged.

Matrix Spike/Matrix Spike Duplicate - Matrix spikes and matrix spike duplicates (MS/MSD) are used to assure that recovery of target compounds is acceptable for the sample matrices involved. The spike duplicates are also used to demonstrate the relative precision of each method. The Relative Percent Difference (RPD) between spike values is calculated and noted. These values generally are calculated, recorded and compared to internal control charts to monitor system performance. Samples may be split during analysis to determine possible matrix interferences.

Data quality indicators associated with MS/MSD samples include both accuracy and precision. Precision of the analytical technique can be estimated using the relative percent difference (RPD) between the analytes of interest in the samples, and can be calculated as follows:

$$RPD = \frac{|C_{MS} - C_{MSD}|}{0.5 (C_{MS} + C_{MSD})} \times 100\%$$

Where:

$$\begin{aligned} C_{MS} &= \text{Concentration in MS} \\ C_{MSD} &= \text{Concentration in MSD} \end{aligned}$$

Accuracy for organic analytes will be estimated by calculating percent recovery (%R) for laboratory MS samples using the following equation:

$$\% R = \frac{(C_s - C_u)}{C_a} \times 100\%$$

Where:

$$\begin{aligned} C_s &= \text{Concentration in spiked aliquot} \\ C_u &= \text{Concentration in unspiked aliquot} \\ C_a &= \text{Actual concentration of spike added} \end{aligned}$$

Surrogate Spike – Surrogates, specified in certain methods, are compounds added to each sample before extraction to measure the efficiency of the extraction. Surrogates are selected according to protocol given in the reference methods and instrument guidelines. Recoveries are determined and reported with sample data on the final report. If recovery is outside the range established by the laboratory, then the results are reported with a qualifying statement identifying the matrix problems encountered.

Method Blank - Laboratory generated sample that is carried through all cleanup and analytical steps to check for contamination during this part of the work. The method blank is generally deionized water for most routine testing, but can be a gas or sand (e.g., if samples are a gaseous or a solid matrix).

6.3 Field Quality Control There are several testing/calibration activities and a number of types of samples that are used to track the field sampling and testing processes to ensure that these processes produce data of satisfactory quality. The QC sample types, frequency, acceptance criteria, and corrective actions are listed in Table 6-1 and associated Field QC Tables.

Table 6-1. Field Quality Control Samples

QC Sample	Frequency	Acceptance Criteria	Corrective Action
Equipment field blank	1 per day of sampling	Below established reporting limits	Modify equipment decon procedures
Trip blank	1 per day of VOC sampling	VOC < RDL	Flag data and modify shipping procedures

Field Quality Control Activities for Critical Measurements Not Specified in the Above Table

Table 6-1-1. Field Quality Control Samples: pH

QC Sample	Frequency	Acceptance Criteria	Corrective Action
Calibration standard (pH 7 and other standard to bracket sample pH)	Start of each measurement period	pH within ± 0.1 pH units	Re-calibrate
Sample duplicate	Twice daily on day of sampling, beginning and end of day	± 0.1 pH units	Re-calibrate; flag data; contact project manager
Standard check (pH 7)	At the end of the sampling day	± 0.1 pH units	flag data

Temperature

The thermocouple will be evaluated annually (e.g., with regard to potential erratic performance) by checking against a second NIST traceable thermocouple. If the readings do not agree within $\pm 1^\circ\text{C}$, the use of the defective, in-place thermocouple will be discontinued and readings from an alternate thermocouple (in the given cell) will be used instead.

Table 6-1-2. Field Quality Control Samples: Waste Density

QC Sample	Frequency	Acceptance Criteria	Corrective Action
Calibration weight series for balance check (4,000 to 24,000 lbs, 3,000 lb increments)	monthly	$\pm 1\%$ true weight for each calibration standard	Re-calibrate balance

Table 6-1-3. Field Quality Control Samples: Gases

QC Sample	Frequency	Acceptance Criteria	Corrective Action
Calibration check certified gas standard for CH ₄ , CO ₂ , and O ₂	Twice daily on day of sampling, beginning and end of day	Within $\pm 15\%$	Re-calibrate instrument; flag data; contact project manager
Sample duplicate for CH ₄ , CO ₂ , and O ₂	One sample duplicate collected in Tedlar bag on sampling day.	Table 6-9	Re-calibrate instrument; flag data; contact project manager
Span gas (zero gas)	Twice daily on day of sampling, beginning and end of day	Not greater than 5% of instrument span	Re-calibrate instrument, flag data, contact project manager

Table 6-1-4 Field Quality Control Samples: Waste Settlement

QC Sample	Frequency	Acceptance Criteria	Corrective Action
Precision evaluation	For every 20 measures, randomly select one of the previous 20 points and resample.	Within ± 5 cm of last recorded horizontal and vertical position	Re-initialize, redo precision evaluation, re-record previous 20 samples.
Initial calibration from known point	At the initialization of each sampling period	Within ± 5 cm of known horizontal and vertical position	Re-initialize

6.4 Laboratory Quality Control Several types of QC samples will be analyzed in the laboratory, including calibration standards. Corrective actions for critical parameters in these samples not meeting QC criteria and for analytical operations are summarized in Table 6-2 through 6-8. Note that other actions may be taken upon review of the analytical results based on considerations such as limited sample volumes, holding time and other technical issues.

Table 6-2 Laboratory Quality Control Activities: Chemical Oxygen Demand

Event or sample type	Minimum Frequency	Acceptance Criteria	Corrective Action
Initial 5 point calibration curve with potassium hydrogen phthalate standards (5 mg/L – 425 mg/L)	Initially and when CCC exceeds criterion. (Every three months at a minimum.)	$R^2 \geq 0.995$ and visual confirmation of linearity (e.g., data points fall close to and on both sides of the line)	Re-calibrate
Continuing calibration check (CCC)	Run mid-point standard with each analytical batch (≤ 20 samples)	$\pm 10\%$ of actual concentration	Re-calibrate and re-analyze affected samples.
Laboratory control sample (Second source check)	Each analytical batch (≤ 20)	$100 \pm 20\%$ recovery	Re-run LCS; check calculation of compounds; Re-run samples as required; contact project manager
Matrix spike with potassium hydrogen phthalate standard	Each analytical batch (≤ 20 samples)	$100 \pm 20\%$ recovery	Re-run spike; check calculation of compounds; Re-run samples as required; contact project manager
Laboratory blank	1 in every set of 10 samples	Below Detection Limit	Investigate problem, check other batch blanks for sample carry over. Eliminate contamination, rerun.
Laboratory duplicate	Run duplicates with each batch (≤ 20 samples)	$\pm 20\%$ RPD	Re-do duplicate: contact client if consecutive duplicates fail.

Table 6-3 Laboratory Quality Control Activities: Biochemical Oxygen Demand

Event or sample type	Minimum Frequency	Acceptance Criteria	Corrective Action
Accuracy check Glucose/glutamic acid standards (5 dilutions)	Prior to running samples and every 20 samples	198 ± 30.5	Reevaluate control limit and investigate, reject tests made with that seed and dilution water
Dilution blank (method blank)	Each batch or every 20 samples	0.2 mg/L difference initial DO and final DO	Investigate problem, check other batch blanks; eliminate contamination, rerun.
Seed control	Each batch or every 20 samples	DO uptake between 0.6 and 1 mg/L, adjust to meet glucose/glutamic acid acceptance criteria	Investigate problem and reject tests made with that seed
Laboratory duplicate	Run duplicates with each batch or every 20 samples	Compare to project QA objectives (Table 6-9)	Re-do duplicate: contact client if consecutive duplicates fail

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Table 6-4 Laboratory Quality Control Activities: Volatile Organic Acids

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action
Initial 5-point calibration curve	Initially and as needed	$R^2 > 0.99$	Re-calibrate
Continuing calibration standard (2 nd Source)	Every sample batch.	Standard reads within 20% of true value	Re-calibrate
Method Blank	Every sample batch	< RDL	Re-run: check for sample carry over; system maintenance
Matrix spike	Every sample batch (≤ 20)	70% -130% recovery of critical compounds	Re-run spike; check calculation of compounds; Re-run samples as required; contact project manager
Laboratory Control Sample	Every sample batch (≤ 20)	70% -130% recovery of critical compounds	Re-run LCS; check calculation of compounds; Re-run samples as required; contact project manager
Laboratory duplicate	Run duplicates with each batch or every 20 samples	Compare to project QA objectives (Table 6-9)	Re-do duplicate: contact client if consecutive duplicates fail

Table 6-5 Laboratory Quality Control Activities: Organic Solids

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action
Sample duplicate	Every sample	$\pm 25\%$ Relative Percent Difference (RPD)	Re-do duplicate; flag data
Calibration weight (1 g) for balance check	Every day before sampling	$\pm 0.1\%$	Re-calibrate balance

Table 6-6 Laboratory Quality Control Activities: Waste Moisture

Event or sample type	Minimum Frequency	Acceptance Criteria	Corrective Action
Calibration weight (1 kg) for balance check	Every day before sampling	$\pm 0.1\%$	Re-calibrate balance

Table 6-7 Laboratory Quality Control Activities: Waste pH

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action
Calibration standard (pH 7 and other standard to bracket expected sample pH)	Start of each measurement period	pH within ± 0.1 pH units	Re-calibrate
pH sample duplicate	Twice daily on sampling day, beginning/end of day	$\pm 15\%$ RPD	Re-calibrate; flag data; contact project manager
Standard check (pH 7)	At the end of measurement period	pH within ± 0.1 pH units	flag data

Table 6-8 Laboratory Quality Control Activities: Biochemical Methane Potential

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action
Triplicate matrix (cellulose) spike (spiked at 30% of est. methane potential)	Once, pending acceptable results	100 ± 20% recovery	Re-run spike; check calculation of compounds; Re-run samples as required; contact project manager
Triplicate subsamples	Every sample	± 20% (RSD)	Investigate problem; Re-do sample; flag data

6.5 Failure to Meet Data Quality Indicators The QA objectives presented in Table 6-9 represent the data quality necessary to establish the characteristics of the site during the various sampling/analysis events and to generate data of sufficient quality to meet the project's technical objectives. The QA/QC efforts discussed in this QAPP focus on controlling measurement error within the precision, accuracy, and completeness (100% completeness is the target for all analyses) objectives given and provide a database for estimating uncertainty in the measurement data for the project. QA objectives for precision and accuracy will be evaluated during each sampling/analysis episode to see if the overall results for the project meet the stated objectives. If these objectives are not met the precision and/or accuracy of the results may be affected. Reanalysis of the samples will be conducted when it can be done. Corrective actions taken in response to non-compliant data will be documented and summarized in the project's final report and the impact on project objectives will be evaluated and discussed.

Of all the objectives listed in Table 6-9 the MSW sampling is most likely to fall short of 100% completeness. Previous landfill sampling has repeatedly shown discrete samples that will be all one type of material, such as wood, plastic, etc. as opposed to normal heterogeneous trash. At each sampling location three MSW samples will be taken per 10' vertical increment. If one of these samples is lost, the analytical results from the other two samples will be used to estimate the average concentration for that location. If more than one sample is lost at a single location, then the location will be re-sampled as near as possible to the location if the drilling equipment is still on site. Otherwise it will be noted in the data report.

Table 6-9. Quality Assurance Objectives for Critical Measurements

Measurement	Matrix	Method	Grab/Field Electrode/ Time Point*	Precision a	Accuracy b	RDLs c	Units
Chemical Oxygen Demand	Leachate	410.4	G	± 20%	100 ± 20%	5	mg/L
Biochemical Oxygen Demand	Leachate	405.1	G	± 20%	100 ± 30%	2	mg/L
Leachate temperature (d)	Leachate	Thermocouple	FE	± 1°C	± 1°C	N/A	°C
pH	Leachate	Field electrode	FE	± 0.1	± 0.1	N/A	-log H+
Volatile Org Acids	Leachate	Microbial Insights SOP	G	± 20%	100 ± 30%	0.1	mg/L

Table 6-9. Quality Assurance Objectives for Critical Measurements con't

Measurement	Matrix	Method	Grab/Field Electrode/ Time Point*	Precision a	Accuracy b	RDLs c	Units
Waste Temperature (d)	MSW	Thermocouple	FE	± 1°C	± 1°C	N/A	°C
Waste Settlement (e)	MSW	GPS Survey	TP	± 5 cm	± 5 cm	N/A	cm
Organic Solids (f)	MSW	Appendix D	G	± 25%	± 0.1%	N/A	%
Moisture Content (f)	MSW	Appendix F	G	± 2%	± 0.1%	N/A	%
pH (g)	MSW	Appendix G	G	± 0.1	± 0.1	N/A	-log H+
Biochemical Methane Potential	MSW	Appendix E	G	± 20%	100 ± 20%	1	ml/g
Waste Density	MSW	Field Calibration	G	N/A	(h)	N/A	kg/m ³
CH ₄ , CO ₂ , O ₂	Gas	See Section 4.4.2	G	(i)	(i)	Appendix C	% (vol)
CH ₄ , CO ₂ , O ₂	Gas	Summa, lab	G	± 10%	± 10%	(j)	% (vol)
Gas Volume (k)	Gas	See Section 4.6	G	± 5%	100 ± 5%	N/A	m ³

* Samples are collected as a grab at the point of collection. GPS measures represent unique temporal/spatial sampling points.

- (a) Precision expressed as the relative percent difference (RPD) between spiked duplicates and/or lab duplicates (biochemical methane potential precision assessed with the relative standard deviation [RSD] of triplicate samples)
- (b) Accuracy is expressed as the % recovery of matrix spikes or as the measurement of a known standard
- (c) RDLs are the reporting detection limits as devised by the lowest calibration standard or weight.
- (d) Precision and accuracy objectives for temperature are based upon thermocouple specifications
- (e) Precision and accuracy objectives for GPS are based upon manufacturer specifications (Trimble model 4800), positioning accuracy determination outlined in section 4.4.3.
- (f) Precision and accuracy objectives for moisture and organic solids are based upon calibration requirements for analytical balances and duplicate weight measures of the same sample.
- (g) Accuracy for pH is based upon known standards. Precision is based on sample duplicate readings.
- (h) Balance is calibrated monthly and must be accurate to ± 1% of true weight.
- (i) Gas composition precision (sample duplicate) and accuracy (certified gas standard) are as follows: methane and carbon dioxide precision, ± 10% (RPD), accuracy, 100 ± 10%; oxygen precision 30% (RPD), accuracy 30%.
- (j) Reporting detection limits for the gases are: CO₂=0.02%; CH₄=0.0004%; O₂=0.2%.
- (k) Gas volume precision and accuracy are based upon manufacturer specifications and factory certification of the flow meter used.

6.6 Retained Sample Storage Outer Loop subcontracted laboratories will store all residual samples and sample preparations until disposal is authorized by WMI. Disposal will be authorized following data review by Nancy Grams for WMI. While waiting for data review and validation, the samples will be stored in the following manner. The residual samples and their preparations will be stored in a refrigerator at 4°C or in a specified storage area at room temperature, depending on the analysis required, for 60 days.

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7.0 DATA REPORTING, DATA REDUCTION AND DATA VALIDATION

For analytical data to be scientifically valid, defensible, and comparable, the correct equations and procedures must be used to prepare the data. Evaluation of measurements is a systematic process of reviewing a body of data to provide assurance that the data are adequate for their intended use. The process includes the following activities:

- Auditing measurement system calibration and calibration verification;
- Auditing QC activities;
- Screening data sets for outliers;
- Reviewing data for technical credibility vs. the sample site setting;
- Checking intermediate calculations; and
- Certifying the above process.

7.1 Laboratory Data Reduction and Reporting This section discusses laboratory data reduction, laboratory data validation, and laboratory-reporting requirements that will be implemented by Outer Loop subcontracted laboratories.

7.1.1 Laboratory Data Reduction The analytical methods to be used for this full-scale applied research project contain detailed instructions and equations for calculating compound concentrations and other parameters. Data for critical parameters will be reduced to the units presented in Table 7-1. The established Reporting Limit (RL; determined by the lowest calibration standard) will be used in reporting results. All results between the RL and method detection limit (MDL) will be reported and flagged as "estimated". All calculable results that fall below the MDL will be flagged signifying that the calculated result was below the MDL and the MDL will be reported. The qualifier indicates the laboratory's judgement as to the limits of the data usability.

The analysts responsible for the measurements will enter raw data into logbooks or onto data sheets. In accordance with standard document control procedures, original copies of all data sheets and logbooks containing raw data – signed and dated by the responsible analyst – will be maintained on file. Separate instrument logs will also be maintained to enable reconstruction of the run sequence for individual instruments.

7.1.2 Laboratory Data Validation Individual analysts will review the data generated each day to determine the need for corrective action or rework. Data reviewed will include calibration and QC data. Individual analysts will also review data for completeness. Data will also undergo a second review process conducted by one of three independent reviewers (under some conditions, this second review may be conducted by an analyst that was not responsible for generating the data he or she reviewed). This second review is typically conducted within several days after the data are generated. The reviewers also review laboratory logbooks and notebooks on a monthly basis. Data books will be initialed and dated when evaluated. Data validation separate from that performed by the laboratories will be performed on 10% of all data.

Table 7-1. Reporting Units For Critical Measurements

Parameter	Units
Leachate	
Chemical oxygen demand	mg/L
Biochemical oxygen demand	mg/L
Volatile organic acids	mg/L
Temperature	°C
Leachate	
pH	-log H+
MSW	
Waste Temperature	°C
Waste settlement (GPS)	Height decrease (-cm) relative to fixed reference
Organic Solids	%
Biochemical methane potential	ml/g
Waste density	kg/m ³
pH	-log H+
Moisture content	%
Gases	
Methane	%
Carbon dioxide	%
Oxygen	%
Gas volume	m ³

7.1.3 Laboratory Reporting and Data Retention Requirements All laboratories will provide a spreadsheet or other electronic database information showing the laboratory data, and general calculations used to determine the final concentration in each parameter/fraction/test. The laboratory will supply the following information in the form of a Level II Report:

- Case narrative including a list of samples reviewed with field name and laboratory names cross-referenced, discussion of any deviations from the QAPP and any other non-conformances and the associated corrective actions, discussion of any analytical or procedural problems encountered and corrective actions, and an explanation of the data qualifiers used
- Completed chain-of-custody forms
- Sample result summary forms for all samples, field QC samples, and method blanks
- Spreadsheet containing any positive or negative results that are between the RL and MDL will be flagged as “estimated”; calculable results below the MDL will be flagged signifying that the calculated result was below the MDL (with MDL reported)
- QC summary forms for MS/MSD samples and other lab QC
- Sample preparation logs and run logs

Original copies of all data sheets and logbooks containing raw data will be signed and dated by the responsible analyst reviewer(s) and will be maintained on file in accordance with standard document control procedures. The laboratory will maintain separate instrument logs to enable the run sequences to be reconstructed for individual instruments. The laboratory will maintain all data on file for 5 years in a secure archive warehouse accessible only to designated laboratory personnel. The data will be disposed of in the interim only after instructions to do so have been received from WMI and EPA. After 5 years, the data will be distributed to EPA and to WMI.

7.2 Project Data Reporting Following the baseline sampling, WMI will prepare a data report. The report will consist of all analytical data. The report will be delivered to EPA 90 days after the pretreatment sampling is completed.

Laboratory validated analytical data submitted by WMI will be used by EPA to prepare reports that evaluate the landfill bioreactor technologies and assess the potential applications. The report will include, at a minimum, the following information:

- A discussion of the procedures used to define data quality and usability and the results of these procedures. Summary tables of the QC data obtained during the demonstration will be included. Results will be compared to the quality assurance objectives set forth in this QAPP to provide an assessment of the factors that contributed to the overall quality of the data.
- The results of any technical system and/or performance audits performed during the course of the project will be documented, including corrective actions initiated as a result of these audits and any possible impact on the associated data. If any internal audits were performed, these too will be reviewed.
- All changes to the original QAPP will be documented regardless of when they were made. The rationale for the changes will be discussed with any consequences of these changes.
- The identification and resolution of significant QA/QC problems will be discussed. Where it was possible to take corrective action, the action taken and the result of that action will be documented. If it was not possible to take corrective action (for example, a sample bottle was broken on transit), this, too, will be documented.
- A discussion of any special studies initiated as a result of QA/QC issues and/or corrective actions, including why the studies were undertaken, how they were performed, and how the results impacted the project data.
- A summary of any limitations on the use of the data will be provided including conclusions on how these constraints affect project objectives.
- The QA section will provide sufficient narrative concerning factors that could affect data (e.g., weather events) used in the evaluation of the landfill bioreactor technology. WMI project personnel will review this section to assess the assumptions made in evaluating the data and the conclusions drawn.

7.3 Reporting The quality-related results, actions, and decisions required by this Quality Assurance Project Plan necessitate a reporting mechanism to keep project management informed as to the project status. These reports, discussed below, represent the minimum requirement to

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provide management with the information necessary to assess the adequacy and success of the QA program.

7.3.1 Schedule A detailed report on quality-related activities will be prepared after each sample set analysis by Nancy Grams and submitted to the Technical EPA Project Co-Managers. Information submitted in this report will include summary laboratory QA/QC activities and an overall tentative assessment of data quality to date. The report will discuss any problem conditions and corrective actions, audit events and results, sampling and analysis QA/QC status, and a general review of the achievement of data objectives for the project.

7.3.2 Final Report The final demonstration report will include a separate QA section that documents the QA/QC activities that support a determination of the credibility and validity of the data. A summary of the data quality information will be provided, including an assessment of the QA objectives which were achieved, those which were not and why, and the expected impact on the project.

8.0 AUDITS Audits are an independent means of confirming the operation or capability of a measurement system, and of independently documenting the use of QC measures designed to generate valid data of known and acceptable quality. An audit is, by necessity, performed by a technically qualified person who is not directly involved with the measurement system being evaluated. A performance evaluation is generally an objective audit of a quantitative nature, and a systems audit is a qualitative evaluation of the capability of a measurement system to produce data of known and acceptable quality. Both types of audits will be performed for the laboratory and the field portions of this full-scale landfill bioreactor demonstration as discussed below.

8.1 Performance Audits For all tests/methods conducted by laboratories, the performance evaluation samples received and processed by the laboratories (just prior to, during, and immediately following their involvement in the project) for purposes of compliance with laboratory certification requirements relating to these analyses (or where the laboratory is not regulated, PE samples submitted blind to analysts by laboratory management) will be provided to WMI. For all failed PE results the laboratory will institute remedial actions and where valid performance of the measurement system cannot be established, the laboratory will establish corrective actions. These corrective actions will include evaluation of testing data that may have been affected, notification to WMI if project data may have been affected, and amended reports with data appropriately qualified if and when the laboratory determines that data have been affected.

Lab data validation procedures are required to employ an independent analyst to review all aspects of data generation, including the calculation steps used to generate sample concentrations. Outer Loop subcontracted laboratories will conduct this activity as part of their normal operations. Upon request to the laboratory, complete data sets (which document the laboratories' data reduction and data review/validation) will be provided to EPA project personnel at no charge by the laboratory. EPA will spot-check these data for compliance with requirements and correctness of results. Results of these performance audits will be reported to the WMI QA Manager and made available for review.

8.2 System Audits A system audit is a qualitative determination of the overall ability of a measurement system to produce data of known and acceptable quality, by an evaluation of all procedures, personnel, equipment, etc. utilized to generate the data. It is an evaluation of whether adequate QC measures, policies, protocols, safeguards, and instructions are inherent in the measurement system to enable valid data generation and subsequent actions. EPA QA personnel will conduct biannual (every two years) field systems audits during this field test.

The field systems audit will review the project organization and technical personnel involved, including the following:

- Use of proper sampling equipment
- Procedures for equipment maintenance and decontamination
- Acceptable sampling protocol
- Calibration procedures for field measurements
- Proper sample handling

Storage and shipping procedures
Adequate field documentation and record-keeping procedures
Data reduction and reporting procedures (to final databases)

Laboratory systems audits of Outer Loop subcontracted laboratories for the methods and analytes critical to the project will be reviewed by WMI where laboratory certification agencies have audited these activities, or audits will be conducted by WMI and by EPA. These audits will be performed on a biannual basis. In addition, the technical abilities of the lab personnel involved with the analysis of demonstration (randomly selected) samples will be reviewed. Regulatory or WMI audits will evaluate instrumentation respect to technical acceptability, maintenance procedures and records, availability of spare replacement parts (and/or service contracts), and general upkeep. Analytical methodology for all critical measurements of the project will be reviewed, including all:

Extraction/preparation steps
Analysis steps
Data reduction and validation procedures
Applicable QC sample analysis records
Calibration records
General record-keeping/documentation practices

Additionally, sample handling and tracking procedures would be evaluated including:
Sample receipt
Chain-of-custody
Sample storage
Sample/standard segregation
Results reporting

8.3 Corrective Action Strictly defined sample and handling procedures, calibration procedures, QC sample analyses, and all associated acceptance criteria are part of the comprehensive QA program designed to identify situations which do not meet specific QA/QC requirements. The specific corrective action steps to be taken in response to failed criteria are discussed in Section 6.0. This section outlines general principles and procedures for identifying and responding to QA problems. Analytical QA and associated corrective actions are conducted by WMI and their analytical subcontractor.

8.4 Initiation of Corrective Action The need for corrective action comes from several sources:

- Equipment malfunction
- Internal QA/QC checks outside of acceptance criteria
- Deficiencies noted during performance or system audits
- Non-compliance with sampling/analysis/QA requirements

In all instances, except for responding to audit findings, personnel (field and laboratory) directly performing the measurement task are responsible for identifying any non-conformance or

potential problem with the protocols, equipment, or method. The responsible individual must immediately notify the appropriate supervisor that a problem exists. If the individual identifying the problem can correct it independently, such corrective action must take place before any further sample collection or analysis occurs. Depending upon the circumstances, the specific steps to be taken and the initiation of the corrective action can be decided by the field/laboratory technician, WMI management, or the laboratory QA Manager.

8.5 Documentation of Corrective Action If, at any time immediate actions do not bring the system into control and without affecting any project data, formal corrective action shall be taken and documented with regard to:

- Actions taken to bring the process back into control.
- Actions taken to prevent recurrences of the out-of-control situation.
- The fate of data obtained while the process was out of control.

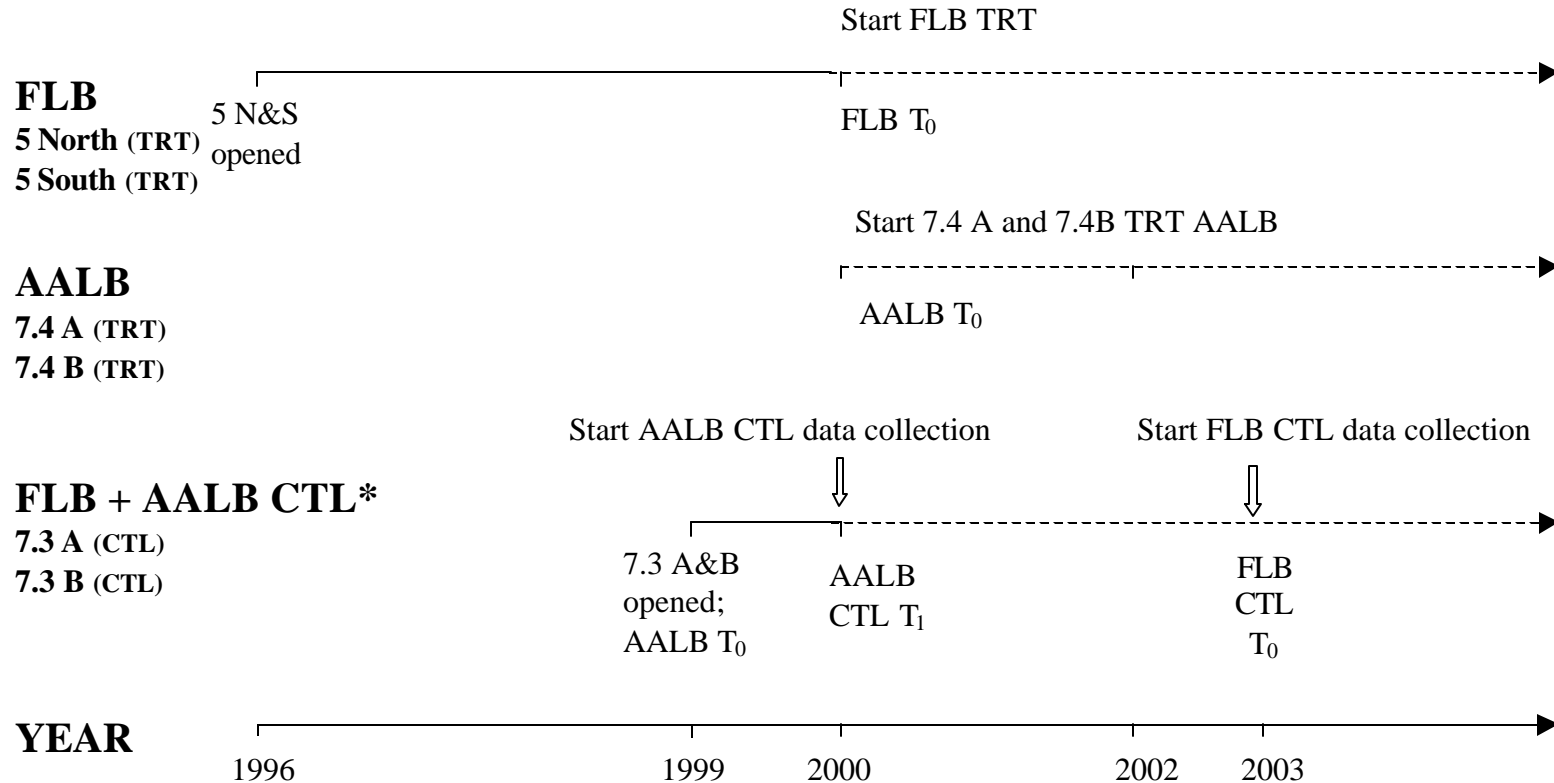
The documentation is accomplished by filing a corrective action report (WMI) or a memo to the file (EPA). Field or laboratory personnel, the appropriate supervisor, or the Laboratory QA Manager, depending on where the problem is recognized, initiates this documentation. The documentation will include as much of the following information as is appropriate to the problem:

- Nature of problem
- Parameter affected
- Sample lot affected
- Personnel responsible for identifying the problem
- Corrective action measure(s) taken and final disposition/resolution of problem
- Dates
- Initials of the field personnel, analyst, or data reviewer

9.0 REFERENCES

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Appendix A. Time Line for Outer Loop Landfill Bioreactor Studies



FLB: Facultative Landfill Bioreactor

AALB: Aerobic/Anaerobic Landfill Bioreactor

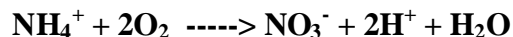
CTL: Control

TRT: Experimental Treatment

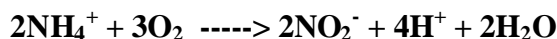
* Because the control cells are, for the most part, younger than FLB cells, the control needs to be monitored longer than the FLB cells.

Appendix B. Microbial Ecology of Nitrogen Transformations

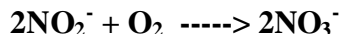
Nitrification is a biological process that converts ammonia ions to nitrite ions and then to nitrate ions. The groups of bacteria that perform this conversion are chemolithotrophic nitrifiers. The conversion occurs according to the overall equation:



The process takes place in two steps and each step is carried out by a distinct group of nitrifying organisms. These organisms are *Nitrosomonas* and *Nitrobacter*. The reactions are as follows.



Nitrosomonas (also *Nitrospira sp.*, *Nitrococcus sp.* and *Nitrosolobus sp.*)



Nitrobacter (also *Nitrospira sp.* And *Nitrococcus sp.*)

Nitrosomonas (and other genera) performs the first step of the conversion by oxidizing ammonium to nitrite. *Nitrobacter* (and other genera) completes the oxidation by converting the nitrite to nitrate.

For more information, the reader is referred to Atlas and Bartha (1987):

Atlas RM, Bartha R. 1987. *Microbial Ecology: Fundamentals and Applications*, Second Edition Benjamin /Cummings Menlo Park, CA pp. 333-342.

Appendix C. Measurements

Field Methane, Oxygen and Carbon Dioxide

Landtec GEM 2000

The GEM 2000 is part of LANDTEC's family of products developed specifically for the landfill industry. These products are based on a decade of operating and regulatory experience at multiple landfill gas to energy sites by LANDTEC's parent, Pacific Energy.

How it works

A high vacuum sample pump draws a quantity of gas through the sample hose, in-line water trap and a user replaceable particulate filter, into a sample chamber. An infrared beam is projected, via sapphire windows, through the gas sample. On the other side of the chamber the beam is sensed by methane and carbon dioxide detectors. A microprocessor calculates the amount of infrared light absorbed at different wavelengths and determines the various gas concentrations.

The oxygen concentration is measured by the Galvanic Cell method. The oxygen molecules diffuse through a Teflon membrane into a cell containing a gold electrode. The molecules are reduced and a current flows between the gold electrode and a lead electrode. The resulting cell output is measured as a voltage which is proportional to the oxygen concentration. The entire system has a very high resistance to poisoning caused by the presence of other gases, such as carbon dioxide or hydrogen sulfide. When a sufficient amount of gas has entered the sample chamber, gas concentration levels shown on the display will stabilize. Data will be stored electronically GEM 2000 memory with I.D. code, date and time in addition to being recorded in the field log. Scott gases or a similar reputable dealer will be used for the gas standards.

sample resolution

	Sensor Range	Resolution
Methane - CH₄*	0 - 100%	0.1%
Carbon dioxide - CO₂*	0 - 60%	0.1%
Oxygen - O₂*	0 - 25%	0.1%
Static pressure*	0 - 100" H ₂ O	0.01" H ₂ O%
Barometric pressure*	±0.15" Hg	0.1" Hg

* Optional features

Accuracy

	%CH ₄ by Volume	%CO ₂ by Volume	%O ₂ by Volume
Concentration			
5% (LEL CH ₄)	±0.3%	±0.5%	±0.25%
60%	±1.9%	±3.0%	n.a.
100%	±1.9%	n.a.	n.a.

Appendix D. Determination of the Organic Solids Content of Refuse

The methodology for Organic Solids is presented below:

1. The procedure begins with samples that have been ground in a wiley mill to pass a 1mm screen. If the dryness of a ground refuse sample is suspect, then re-dry it for one day in a 65°C oven. To re-dry ground refuse samples in Mason jars, do the following: Remove the jar lid and cover the mouth of the jar with aluminum foil. Replace the threaded outer ring. Using a disposable 18-gauge needle, punch lots of holes in the aluminum foil. Put the jar into a 65°C oven for at least one day. When the refuse is dry, remove the jar from the oven. Work quickly, as the dried refuse will immediately begin to absorb moisture from the air. Unscrew the threaded outer ring and replace the aluminum foil with the metal lid. Replace the threaded outer ring, screwing it down tightly.
2. Prepare Gooch crucibles and filters by inserting a glass fiber filter (Whatman 934AH) into a crucible. Rinse the crucible with deionized water and place the crucible and filter in the furnace at 550°C for one hour. Allow crucibles to cool in a desiccator. After cooling, store the crucibles in a place where they will be protected from dust and dirt. A clean box with a secure lid, or a tray lined with paper towels and covered with aluminum foil, is ideal for this purpose. NOTE: Once crucibles have been cleaned in this way, do NOT handle them with your fingers; use tongs or a clean, gloved hand only.
3. Place approximately 1 gram of sample in a Gooch crucible. Dry the sample in the crucible at 75°C for at least 24 hours. Carefully stir the refuse approximately 6 hours into drying time. After drying, allow 2 hours to cool in a desiccator. Then, weigh the crucible and dried solids to 4 decimal places. When weighing, work quickly and with one crucible at a time because the dried solids will immediately begin to absorb moisture from the air upon removal from the desiccator.
4. Place the Gooch crucible containing the solids in a 105°C furnace. Increase the furnace temperature to 550°C. Allow the furnace to remain at 550°C for 2 hours, then reduce the temperature to 105°C. After the oven cools to 105°C, remove the Gooch crucible and allow 2 hours to cool in a desiccator.

Weigh the crucible again. When weighing, work quickly and with one crucible at a time because the dried solids will immediately begin to absorb moisture from the air upon removal from the desiccator. The percent weight loss on ignition represents total organic matter.

Appendix E. Biochemical Methane Potential Medium

The BMP procedure was modified from previously developed procedures [5, 23]. Tests are conducted in 125 mL serum bottles (Wheaton, Millville, NJ) sealed with black butyl rubber stoppers (Bellco Biotechnology, Vineland, NJ) and aluminum crimps. Medium composition is presented in Table 1. The N₂/CO₂ (80/20) gas mixture is passed over a hot copper column to remove traces of oxygen.

The carbon source in the BMP test was Wiley-milled refuse obtained as described above. Sufficient refuse is used in each BMP test so that the theoretical methane potential, based on complete cellulose and hemicellulose conversion to methane, was 50 mL. Theoretical methane potential is calculated using the stoichiometry presented in equation 1 [7]. Using equation 1, the calculated methane potential of cellulose (C₆H₁₀O₅) and hemicellulose (C₅H₈O₄) is 415 and 424 mL CH₄ at STP per dry g of cellulose and hemicellulose, respectively.



BMP tests are inoculated with 15 mL of anaerobically digested sludge (obtained just before use) at a gassing station (using the Oxygen-scrubbed N₂/CO₂ gas mixture) with the stopper off. Tests are conducted in triplicate and incubated at 37°C. Background methane production associated with the inoculum is measured in a set of five controls.

To measure gas production, we vent the serum bottle to a gas bag and then measure the volume in the gas bag by using a syringe. Gas volumes are corrected to dry gas at STP. Gas production was measured after 28 days and again after 43 days. **(We now are incubating for 60 days based on the behavior in most recent tests in which gas production did not stop at day 43.)** The absence of additional methane production on Day 43, after correction for background, suggests that biodegradation of the refuse samples was essentially complete.

Additional Notes

With respect to the amount of solids to add, we are adding 1 gm for samples where we have cellulose, hemicellulose data and know that the theoretical gas potential is <170 ml/gm. For all other samples, we are adding 0.5 gm. The volumes to add are based on the size of your serum bottle and the headspace. We use a 160 ml serum bottles with about a 60 mL headspace. As a rule, I would like to keep the overpressure to 60-100 mL. Remember also that there will be some background methane production from the inoculum that must be measured. We do tests in triplicate plus 5 inoculum blanks.

TABLE 1. BMP MEDIUM COMPOSITION

Component	per liter
PO ₄ solution	100 mL
M3 solution	100 mL
Mineral solution	10 mL
Vitamin solution	10 mL
Resazurin (0.1%)	2 mL
Distilled water	768 mL
Refuse	50 mL CH ₄ potential (see text)
NaHCO ₃ ^a	3.5 g
Cysteine hydrochloride (5%) ^a	10 mL

^a Added after adjustment of the media to pH 7.2 and boiling under an 80/20 mixture of N₂/CO₂.

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Component	per liter
KH ₂ PO ₄	16.1 g
Na ₂ HPO ₄ •7H ₂ O	31.89 g

Prepare in carbonate-free water and store under N₂ at 4 °C.

M3 Solution

Component	per liter
NH ₄ Cl	10 g
NaCl	9 g
MgCl ₂ •6H ₂ O	2 g
CaCl ₂ •2H ₂ O	1 g

Store solution at 4°C.

Trace Mineral Solution

Component	1 liter
Nitrilotriacetic Acid	1.5 g
FeSO ₄ •7H ₂ O	0.1 g
MnCl ₂ •4H ₂ O	0.1 g
CoCl ₂ •6H ₂ O	0.17 g
CaCl ₂ •2H ₂ O	0.1 g
ZnCl ₂	0.1 g
CuCl ₂ •2H ₂ O	0.02 g
H ₃ BO ₃	0.01 g
Na MoO ₄ •2H ₂ O	0.01 g
NaCl	1.0 g
Na ₂ SeO ₃	0.017 g
NiSO ₄ •6H ₂ O	0.026 g
Na ₂ WO ₄ •2H ₂ O	0.033 g

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Dissolve the nitrilotriacetic acid in 200 mL of hot distilled H₂O and then adjust the pH to 6.5 with KOH. Add this solution to about 600 mL of distilled water and dissolve the components in the order listed. Dilute to one liter. Store in the refrigerator under nitrogen.

Vitamin Solution

Vitamin	g per liter
Biotin	0.002
Folic Acid	0.002
B ₆ (pyridoxine) HCl	0.01
B ₁ (thiamine) HCl	0.005
B ₂ (riboflavin)	0.005
Nicotinic Acid (niacin)	0.005
Pantothenic Acid	0.005
B ₁₂ (cyanocobalamin) crystalline	0.0001
PABA (P-aminobenzoic acid)	0.005
Lipoic Acid (thioctic)	0.005
Distilled Water	1000 mL

Add ingredients in the order given and let dissolve. Store in a dark container in the refrigerator under nitrogen.

Resazurin Solution

Prepare a 0.1% Resazurin solution (by weight) and store at 4°C.

Cysteine Solution

- 1) Prepare a 5.0% Cysteine Hydrochloride Monohydrate solution (by weight) by first boiling the DI water in a round bottom flask under N₂ (g).
- 2) Add preweighed amount of Cysteine to the round bottom flask.
- 3) Transfer the solution to a serum bottle. Cap the bottle with a butyl rubber stopper and aluminum crimp.
- 4) Autoclave the serum bottle. Let the solution cool before using.

Appendix F. Procedure for Moisture Content Analysis

1. Mix sample in a large container.
2. Label and weigh a dry empty baking pan.
3. Place one to two kilograms of sample into the pan. It may be necessary to dry a sample in more than one pan. Weigh pan(s) and sample(s).
4. Subtract pan weight from total weight for the initial refuse weight.
5. Cover the pan with aluminum foil and poke several holes in the foil using an 18-gage needle or something similar. The holes allow moisture to escape
6. Dry in oven at 65°C.
7. Remove pan from oven and weigh daily until the moisture content weight difference is less than one percent. $(\text{Weight}_{n-1} - \text{Weight}_n) / (\text{Weight}_{\text{day0}} - \text{Weight}_n) * 100\%$. N=day.
8. Subtract recorded pan weight from total dry weight for the final refuse dry weight.
9. Calculate the percent moisture:
 $(\text{initial wet refuse wt.} - \text{final refuse dry weight}) / (\text{initial refuse wet weight}) * 100\%$
8. Remove the dried sample and place it in a labeled plastic bag.

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Appendix G. Procedure for Waste pH

1. Make a slurry of the waste with approximately 250 mls deionized water to 100 g waste. The ratio of water to waste will vary depending on the initial waste moisture (waste will become progressively more moist over time and will require less diluent)
2. Calibrate pH meter with pH 7 standard and another standard (e.g., pH 3) expected to bracket slurry pH.
3. Record the slurry pH
4. Verify that pH is bracketed within the standards used.
5. If slurry pH is outside of range, recalibrate pH meter with appropriate standards and reanalyze.

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Appendix H. Sampling Diagrams (provided as a separate attachment by WMI on an “as needed” basis)

Appendix I. Examples of Exploratory Data Analysis Plots and the Mann-Kendall Test

What follows is a brief summary of the types of exploratory plots recommended in Section 3.3, along with an example of each type of plot. An example of the Mann-Kendall test with contrived data sets is also included to show how two time series might be compared. These lines of evidence can be combined to present a compelling visual and quantitative argument for or against the efficacy of a treatment.

Time plot: Figure I.1 shows an example time plot. The x-axis represents time and the y-axis represents concentration. Individual results are plotted and connected with a line. Detects and non-detects may be plotted as different symbols. When two or more sites are being compared, they are often shown on the same time scale – one on top of the other to facilitate visual comparisons. Horizontal lines can be drawn at concentrations of interest, such as the zero, the overall mean, or some comparison value, such as a regulatory limit.

Box plot: Figure I.2 shows an example of side-by-side box plots. Box plots summarize information about the shape and spread of the distribution of concentrations from a data set. Box plots consist of a box, a (median) line across the box, whiskers (lines extended beyond the box and terminated with a perpendicular line segment), and points outside the whiskers. The y-axis displays the observed concentrations of the data in the appropriate units. The area enclosed by the box shows the concentration range containing the middle half of the data; that is, the lower box edge is at the first or lower quartile of the data (Q1, also called the 25th percentile, 25% of the data fall below Q1), and the upper box edge is at the third or upper quartile of the data (Q3, the 75th percentile; 25% of the concentrations fall above Q3). The height of the box (the interquartile range, Q3-Q1) is a measure of the spread of the concentrations. The horizontal line across the box represents the median (50th percentile or second quartile) of the data, a measure of the center of the concentration distribution. If the median line divides the box into two approximately equal parts, this indicates that the shape of the distribution of concentrations symmetric; if not, it indicates that the distribution is skewed or nonsymmetric. Frequently, the full set of concentrations is plotted as points overlaying the boxplot. When a data set contains results for both detects (detected chemical concentrations) and nondetects (nondetected chemicals reported as less than a sample specific detection limit), it is standard to use different plotting symbols for the detects and the nondetects.

Bubble plot: Figure I.3 shows an example bubble plot. A 2-dimensional bubble plot is one in which the results are classified based on detect status and/or matrix. A different color or line type represents each class. The circles, or bubbles, are different sizes based on concentrations and these bubbles are plotted on a map of the site. The size of the bubble is directly proportional to the relative concentrations in the data set; in other words, the relatively smaller concentrations get smaller bubbles and the relatively larger concentrations get larger bubbles. Refer to the legend of the figure for the classes (including associated color or line type) and bubble size.

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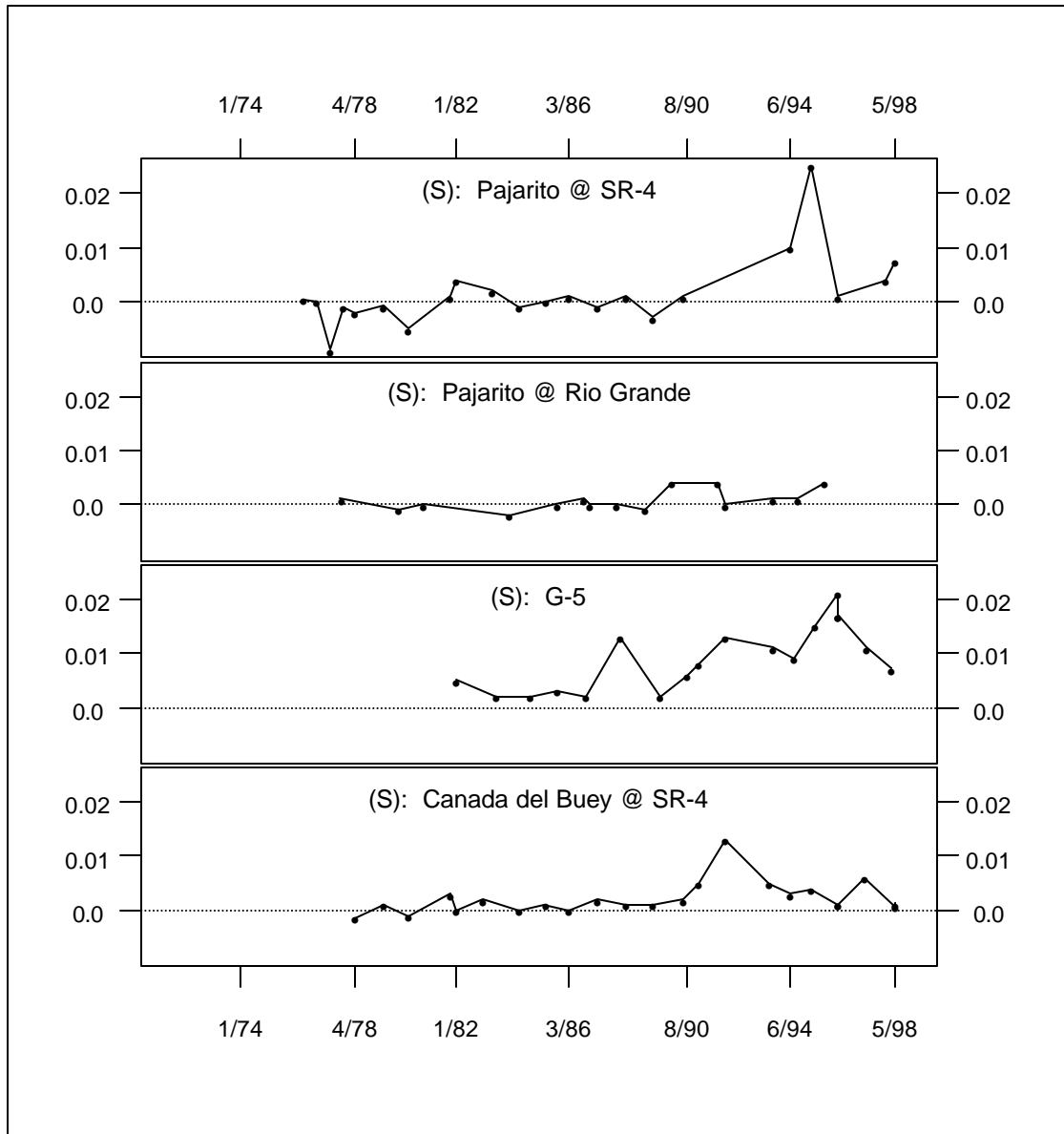
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3D Color Scale Plot: Figure I.4 shows an example of a color scale plot. A color scale plot is one in which the color associated with a result is based on the analyte concentration. In these figures, the color scale ranges from aqua to magenta, with aqua representing relatively lower concentrations and magenta representing relatively higher concentrations. Refer to the legend of the figure for the color/concentration relationship.

This figure provides a 3-dimensional perspective of the core data; a basic cube is plotted on each figure, with the shoreline represented by a bold solid blue line and the land surface approximated using a spline fit on the surface elevation data. The depths of samples are shown relative to surface elevation information provided in the data. One must picture the north-south/east-west plane as going into the page and the surface/depth plane from the top to bottom of the page. A vertical line located inside the cube represents each core. The results are plotted along the vertical line at the corresponding depth at which aliquots from the core were analyzed; the color provides an indication of concentration.



(S): statistically significant increasing trend $p \leq 0.10$

Figure I.1 Example Time Plot

Figure I.2 Example Boxplot.

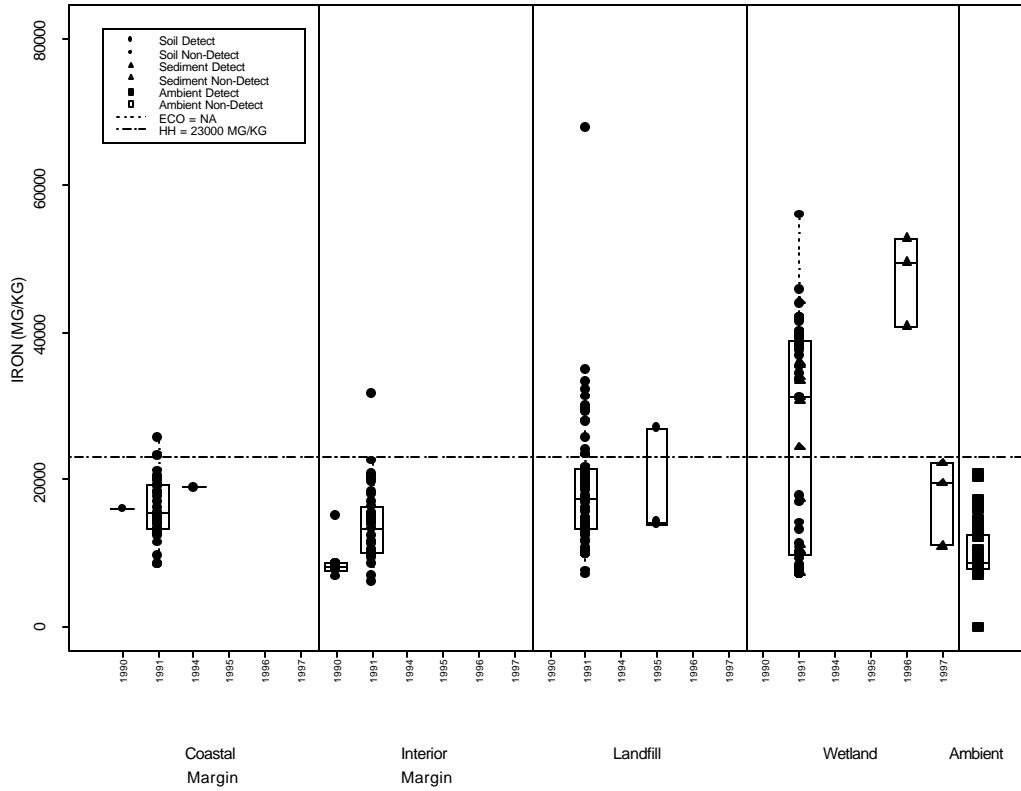


Figure I.3 Example Bubble Plot.

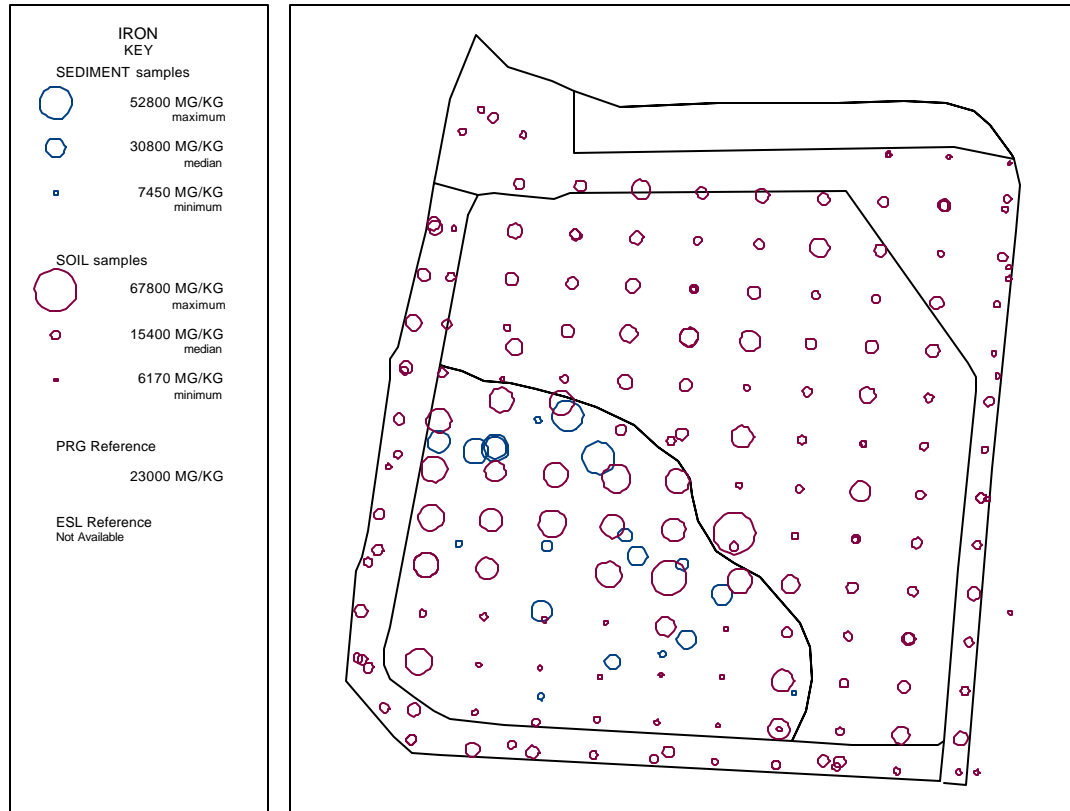
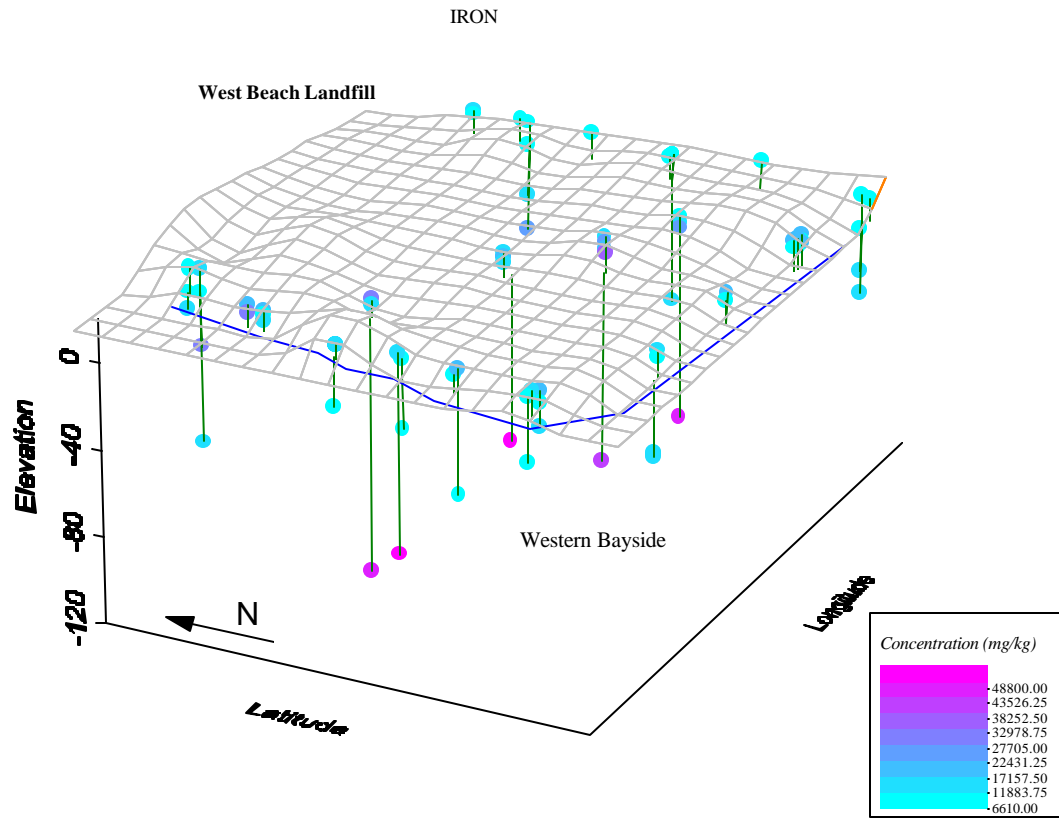


Figure I.4 Example Color Scale Plot



For the example of the Mann-Kendall test, the following data sets were contrived. Suppose that the variable measured is one that increases with time. If the treatment were effective, the rate at which concentrations increase would be greater for the treatment than for the control. The treatment and control data sets were generated from a linear equation with random noise added. The treatment data set used the equation: $\text{concentration} = 20 + 4 * (\text{time step}) + \epsilon$, where ϵ is a realization from a $N(0,5)$ distribution. The control data set used the equation: $\text{concentration} = 20 + 2 * (\text{time step}) + \epsilon$, where ϵ is a realization from a $N(0,5)$ distribution. So, the treatment concentrations are increasing at twice the rate of the control concentrations. Table I.1 shows the data sets and the differences between them.

Figure I.5 shows a time plot of the treatment and the control on the same plot, with linear regression lines drawn for each. Figure I.6 shows a time plot of the differences (treatment-control). The Mann-Kendall test was performed on each data set individually, as well as on the differences between them. The null hypothesis for the Mann-Kendall test is that there is no trend. If the p-value is small (less than 0.05), there is evidence that the null hypothesis is false and that there is a trend. The resulting p-values are shown in Table I.2. Notice that each data set shows an increasing trend, but the differences also show an increasing trend, which is what one might expect if the treatment was effective. If the treatment was not effective, the treatment and control concentrations might both still increase, but at similar rates. Consequently, the differences would not show any trend.

Table I.1 Example Data Set for Mann-Kendall Test.

Time Step	Treatment	Control	Treatment-Control
1	16	18	-1.3
2	34	27	6.9
3	40	22	18
4	40	23	17
5	37	37	0.32
6	48	39	9.6
7	36	45	-9
8	58	30	29
9	50	39	11
10	63	52	10
11	65	34	31
12	69	51	19
13	77	43	34
14	77	46	31
15	82	55	27
16	84	49	35
17	95	61	35
18	80	52	28
19	100	49	51
20	100	53	50
21	98	66	32
22	110	63	48
23	110	62	53
24	130	72	56
25	120	75	44

Figure I.5 Time Plots of Example Data.

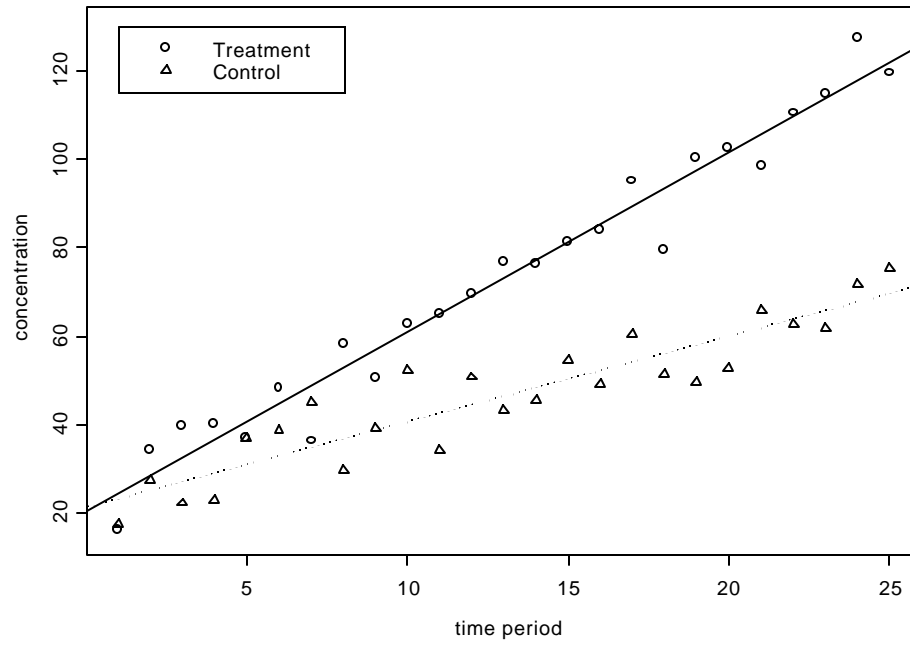
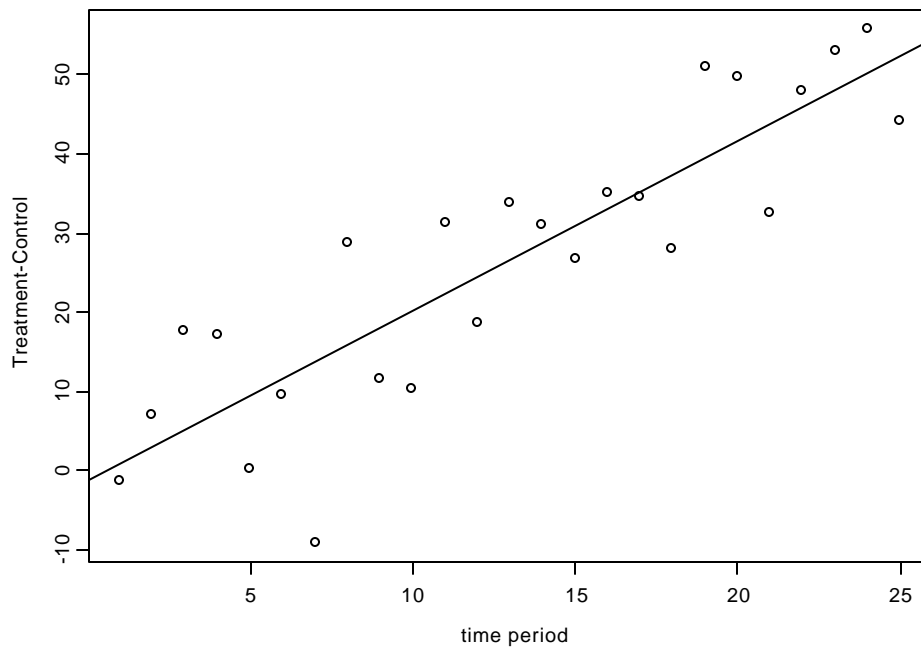


Figure I.6 Time Plots of Differences of Example Data.



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**Table I.2 Mann-Kendall Trend Test
P-values for Example Data Set**

	P-value
Treatment	2.46e-010
Control	5.27e-008
Treatment-Control	1.68e-006

Appendix J. Hazardous Air Pollutants to be Analyzed

Freon 12 (Dichlorodifluoromethane)
 Methyl chloride (Chloromethane)
 Freon 114 (1,2-Dichloro-1,1,2,2-tetrafluoroethane)
 Vinyl chloride (Chloroethylene)
 Methyl bromide (Bromomethane)
 Ethyl chloride (Chloroethane)
 Freon 11 (Trichlorofluoromethane)
 Vinylidene chloride (1,1-Dichloroethene)
 Dichloromethane (Methylene chloride)
 Freon 113 (1,1,2-Trichloro-1,2,2-trifluoroethane)
 1,1-Dichloroethane (Ethylidene chloride)
 cis-1,2-Dichloroethylene
 Chloroform (Trichloromethane)
 1,2-Dichloroethane (Ethylene dichloride)
 Methyl chloroform (1,1,1-Trichloroethane)
 Benzene (Cyclohexatriene)
 Carbon tetrachloride (Tetrachloromethane)
 1,2-Dichloropropane (Propylene dichloride)
 Trichloroethylene (Trichloroethene)
 cis-1,3-Dichloropropene (cis-1,3-dichloropropylene)
 trans-1,3-Dichloropropene (trans-1,3-dichloropropylene)
 1,1,2-Trichloroethane (Vinyl trichloride)
 Toluene (Methyl benzene)
 1,2-Dibromoethane (Ethylene dibromide)
 Tetrachloroethylene (Perchloroethylene)
 Chlorobenzene (Phenyl chloride)
 Ethylbenzene
 m-Xylene (1,3-Dimethylbenzene)
 p-Xylene (1,4-Dimethylbenzene)
 Styrene (Vinyl benzene)
 1,1,2,2-Tetrachloroethane
 o-Xylene (1,2-Dimethylbenzene)
 1,3,5-Trimethylbenzene (Mesitylene)
 1,2,4-Trimethylbenzene (Pseudocumene)
 m-Dichlorobenzene (1,3-Dichlorobenzene)
 Benzyl chloride (-Chlorotoluene)
 o-Dichlorobenzene (1,2-dichlorobenzene)
 p-Dichlorobenzene (1,4-dichlorobenzene)
 1,2,4-Trichlorobenzene
 Hexachlorobutadiene (1,1,2,3,4,4-Hexachloro-1,3-butadiene)
 Hexane
 Methyl ethyl ketone
 Methyl isobutyl ketone
 Acrylonitrile

APPENDIX C

DATA VALIDATION REPORTS

**USEPA/Office of Research and Development
National Risk Management Research Laboratory**

INDEPENDENT DATA VALIDATION

Independent Data Validation of
Outer Loop Landfill Baseline Data

Performed by:

Neptune and Company

Date of Review: 4/30/2002

Baseline Data: 4th Quarter 2001

Data Packages Dates:

STL-Buffalo 12/12/2001

STL-Los Angeles 1/4/2002

NCSU Sample Collection Dates: 6/6/2000-6/30/2000

Waste Settlement Measurements: 7/2001, 10/2001, 1/2002

Task No: 39

EPA Task Order Manager: Ann Vega

Introduction: Baseline data collection is in progress for the Landfill Bioreactor Studies at the Outer Loop Landfill, Louisville, Kentucky. These activities are guided by the Quality Assurance Project Plan, latest revision (Draft Final) dated September 21, 2001. The purpose of this task is to review and validate the data obtained in this project. To accomplish this, data were obtained from Roger Green, Waste Management Incorporated. The data packages included results from Severn Trent Services (STL Buffalo) for leachate sampling performed on November 15, 2001. This report included analysis for Volatile Organic Acids that was subcontracted to Microbial Insights; Severn Trent Services (STL Los Angeles) for gas sampling performed on December 19, 2001; electronic data for MSW analysis (NCSU), and settlement data (WMI). The data represent at least one full set of quarterly results (see QAPP Section 3.0 for sampling schedule). This validation process reviewed all critical and non-critical analyses included in the data packages and outlined in the QAPP Section 3.2, tables 3-4 to 3-6. The results of the data validation are outlined below and categorized by Medium and Laboratory/Analyst data package.

Data packages were evaluated (where appropriate) for Sample Identification (QAPP Section 4.7.1), Chain of Custody (QAPP Section 4.7.3), Correct Analytical Methods (QAPP Table 5.1), Container Preservation and Holding Times (Table 4-1), Detection/Reporting Limits (QAPP Table 6-9) and Laboratory Quality Control for Critical Measurements, QAPP Section 6.4 (Tables 6-2 to 6-9).

Due to the limited amount of QC information provided in the standard (e.g. Level II) data packages, STL-Buffalo, STL-Los Angeles, and Microbial Insights were contacted to obtain raw data for the critical measurements. Data were obtained from all three laboratories and the validation results are included. Additional raw data were not requested from North Carolina State University as this laboratory had been audited, and data evaluated on April 11, 2001.

Overall the results from data validation indicate most laboratory analyses are in compliance with the QAPP quality control requirements. Findings, Observations, and Additional Technical Comments are provided in the section relevant to the issue.

Leachate Samples:

Severn Trent Services-Buffalo. Quote NY95-481. Samples Received 11/16/01. Sample Date 11/15/01. Program Manager: Amy L. Haag.

Client Sample ID	Laboratory Sample ID
51A L01	A1B44001
51B L01	A1B44002
52A L01	A1B44003
52B L01	A1B44004
73A L01	A1B44005
73B L01	A1B44006

General:

The Chain of Custody lists the bottle types but not preservative information as specified in Section 4.7.3 of the QAPP. The samples were grouped consistent with the expected preservatives (e.g. TKN, NH₃, COD, total-P were in a single container consistent with sulfuric acid preservation). The COC does not list the required BOD analysis that was performed.

OBSERVATION (1): The Chain of Custody (COC) should include the preservatives per the QAPP. BOD analysis should be included on the COC.

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Chemical Oxygen Demand (QAPP QC Activities Table 6-2): Method 410.4, STL SOP No. AWC-COD-44:

All six samples were found above the RDL (Table 6-9). But the only sample with no dilution, 73B l01, had a RL of 10 mg/L. The QAPP specified RDL is 5 mg/L. To evaluate the QC requirements specified in Table 6-2 and 6-9 (precision, accuracy) and the Lab SOP, copies of the logbooks were obtained separately from the data package. The log book shows that the QC requirements for ICV, CCV, ICB, second source standard, reactor temperature and dilutions met the requirements and reported data. It was noted that the matrix spike was not performed on the OLL samples but on one other sample from the analytical batch. Blanks on the log book are noted as "< 5", indicating that an RDL of 5 mg/L can be obtained if necessary.

OBSERVATION (2) COD reporting detection limit must be met as specified in the QAPP. Matrix spikes should be performed on OLL samples in future analyses.

Biochemical Oxygen Demand (BOD₅, QAPP QC Activities Table 6-3): Method 405.1, STL SOP No. AWC-405.1-14:

All six samples were analyzed for BOD. QAPP requirements outlined in Table 6-3 were met with the exception of sample duplicates (see Finding 1.0). The data package narrative states that samples 51A L01 and 51B I01 were initially analyzed within the holding time, however all the oxygen was depleted. These samples were re-analyzed outside of the holding times and both sets of data were reported. The reported results for these samples were reported as follows:

51A L01 (detection limit 20) 384 mg/L (flagged as an estimate)

51A L01 (detection limit 2) 221 mg/L (second analysis, out of hold, no flag on report page)

51B L01 (detection limit 20) 384 mg/L (flagged as an estimate)

51B L01 (detection limit 2) 303 mg/L (second analysis, out of hold, no flag on report page).

Review of the logbook (additional raw data requested from STL) shows that the initial analysis resulted in insufficient oxygen depletion (difference between the initial DO and final DO must be greater than 2 mg/L) for the test. This is in contrast to the data package narrative which states oxygen was depleted on the first analysis. The results of the re-analysis in triplicate (raw data, three different dilutions) varied widely:

51A L01: 87.3 mg/L, 154 mg/L, 422 mg/L, average = 221 mg/L

51B L01: 184 mg/L, 422 mg/L, average, = 303 mg/L (With the third sample the final DO value was less than 1 making the analysis invalid)

FINDING (1): Two BOD samples required re-analysis past the holding times. The missed holding times is a concern. Fortunately, in discussion with Roger Green it was learned this was not a common occurrence. The 48 hour holding time criterion means any sample that does not have a valid analysis completed at the end of the 5 day test will fail this holding time. With such variation in BOD, the laboratory is apparently meeting the holding times by setting up several sample dilutions in the first analysis. However, there is concern that the variability observed in the BOD analysis will make comparison between cells difficult. Inspection of the raw data allowed comparison of replicate samples. No “sample duplicates” at the same dilution was performed in this batch. BOD analysis on this organic rich and microbiologically active matrix can be challenging. The project participants should contact STL-Buffalo and discuss the variability in BOD results to see if improvements can be made. Sample duplicates with OLL samples needs to be performed. It may be useful to analyze these samples for CBOD₅ (nitrogenous oxygen demand inhibited) as an evaluation of this matrix effect.

Non-Critical Measurements:

Volatile Organic Compounds, Method 8260:

All six samples were analyzed for VOCs. Due to excessive foaming in the purge vessel all samples were diluted at a ratio of at least 1:10. The blank samples met the

criteria for contamination, surrogate and internal standard recoveries. Surrogate and internal standard recoveries were not reported for the test samples and therefore not reviewed. Surrogate and internal standard recoveries will be requested for data validation in future data packages.

Semi-Volatile Organic Compounds, Method 8270:

All six samples were analyzed for SVOCs. Dilution, due to the matrix effects, was performed on three of the samples. The data package narrative states, “Samples 51B L01 and 52A L01 exhibited surrogate recovery results below quality control limits for all surrogates. However, the internal standard results were compliant.” QC data containing the surrogate and internal standard results were obtained directly from STL. Surrogate recoveries for these two samples were very low (0-18%) indicating a large matrix effect (not due to dilution). This indicates results for these samples are probably biased low (in fact 52A L01 was reported as ND for all 8270 analytes).

OBSERVATION (3): Surrogate recoveries for two leachate samples analyzed by 8270 had very poor results. This indicates matrix effects, probably occurring during the extraction procedure. The potentially poor extraction could be the reason no analytes were observed in 52A L01. It is recommended that matrix spike analysis be performed on these samples to evaluate the extent of matrix effects. In general, matrix spikes should be performed on the OLL samples for all tests that are amendable, especially COD (critical measurement).

RCRA Metals, Methods 6010B, 7470 (mercury):

All six samples were analyzed for RCRA metals. The report included all metals reported as specified on bottom of QAPP Table 5.1. Potassium analyses required dilution for 51B and 52A (noted in data package narrative). However, all samples were reported with the same detection limit (5 mg/L) even though dilutions were required for some samples. Blank results were all reported as ND.

OBSERVATION (4): The Detection Limits reported for the RCRA metals are not easily derived from a comparison of samples that have different dilutions. This potential discrepancy should be clarified with STL-Buffalo.

Wet Chemistry Analysis:

Analysis	Analytical Method
Ammonia (as N)	350.1
Chloride	300.0
Electrical Conductance (Field)	120.1
Nitrite (as N)	353.2*
Nitrate (as N)	353.2
pH (Field)	150.1
Ortho Phosphate	365.2
Total Phosphate	365.2
Sulfate	300.0
Temperature (Field)	170.1
Total Dissolved Solids	160.1
Total Kjeldahl Nitrogen	351.2

The method used for nitrite analysis is 353.2. This is correct per the STL audit conducted July 18, 19, 2001. The QAPP lists method 354.1. This needs to be corrected.

ADDITIONAL TECHNICAL COMMENT (1): The QAPP needs to be modified to include the correct method (353.2) for nitrite analysis.

All six samples were analyzed for the complete suite of wet chemistry analytes. Ammonia, chloride, ortho and total phosphate, and Total Kjeldahl Nitrogen required dilutions in all samples with the exception of 73B L01 due to high concentrations.

The QAPP specified holding time for nitrite and nitrate is 48 hours. Sampling occurred from 11:35- 15:09 on 11/15/2001. Technically, all the nitrate and nitrite analysis have missed the holding time as the analysis was performed at 15:45 on 11/17/2001. The report indicates the holding time was met.

OBSERVATION (5): The holding times issue identified with nitrite/nitrate should be reviewed with STL-Buffalo.

No lab pH measurements reported.

OBSERVATION (6): STL-Buffalo is not performing pH measurement of the leachate (non-critical). Roger Green indicated that a decision was made to only do pH in the field and conductance would be done both in the field and in the laboratory. Review of the Technical System Audit report from STL-Buffalo, QAPP Modifications item #2 indicates the agreement was to perform pH both in the field and lab and only do conductance in the field. Only electrical conductance from the field is reported in the STL data package. It is reasonable to expect conductance to be more stable than pH from field to laboratory but this issue should be resolved and the QAPP modified if necessary.

Microbial Insights, Rockford TN. Point of Contact: Michael Goodrich.
Sample Date 11/15/2001, Analysis Date 11/16/2001.

Client Sample ID	Laboratory Sample ID
51A L01	A1B63901
51B L01	A1B63902
52A L01	A1B63903
52B L01	A1B63904
73A L01	A1B63905
73B L01	A1B63906

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Volatile Organic Acids, Microbial Insights, Point of Contact: Michael Goodrich. SOP No. VFA, Revision 1. (QAPP Table 6-4)

Raw QA/QC data were obtained for samples analyzed on November 15, 2001. The initial calibration data and blank met the requirements outlined in Table 6-4. The CCV and LCS samples have low recovery for Pyruvic acid (40-50% at 4 ppm). The laboratory has since started using the midpoint level (40 ppm) for CCV. The low recovery for Pyruvic acid indicates results for this analyte may be biased low, however no pyruvic acid was detected above the reporting limits found in the STL report (this work is subcontracted to Microbial Insights). However, the QAPP lists the RDL of 0.1 (Table 6-9) yet the lowest standard run is 1 mg/L. The project participants should decide if an

RDL of 1 mg/L is sufficient for the project objectives. Michael Goodrich indicated they had not performed matrix spikes this day. Michael Goodrich submitted a spreadsheet with 32 days of MS/MSD (using OLL samples) and LCS results obtained after November 15, 2001. The LCSs met the criteria (70-130% recovery) for all compounds with the exception of 12/19/2001. On this day acetic acid recovery was 69.8%. Matrix problems were indicated on several days due to spike recoveries outside the limits.

OBSERVATION (7): The project participants should decide if the reporting limits from Microbial Insights is sufficient and modify the QAPP as necessary. The QAPP (Table 6-4) requires re-analysis of spike and samples if necessary to resolve matrix problems. This should be done in future analyses to determine if the results can be improved. Microbial Insights should contact Roger Green for guidance if re-analysis results in recoveries outside the limits.

Gas Samples:

Severn Trent Services- Los Angeles. STL Lot Number M1L200214. Samples Received 12/20/2001, Date Sampled: 12/19/2001. Project Manager: Marisol Tabirara.

Client Sample ID	Laboratory Sample ID
51 G01	51 G01
52 G01	52 G01

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Fixed Gases (Carbon Dioxide, Methane, Oxygen): Method 3C (QAPP Table 6-9).

Review of the data package for Method 3C indicates the data met the QC requirements for precision and accuracy for the LCS and LCS duplicate. LCS samples had a recovery of 102 and 104% for carbon dioxide and 101 and 101 for methane. Extended raw data and sample QC data was obtained from STL-Los Angeles. Table 6-9 QA objectives for this test are listed as “To be determined.” The raw data show compliance with Method 3C requirements for initial and ongoing calibration. Sample results and RDLs are provided below for reference in determining QC objectives.

Compound	51 G01	52 G01	Reporting Limit
CO2	38%	39%	0.017%
CH4	52%	54%	0.00034%

O2	1.7%	1.1%	0.17%
N2 (not analyte per QAPP)	7.2%	4.6%	1.7%

Non-Critical Measurements:

Total Non-Methane Hydrocarbons: Method 25C Modified

The data package from Roger Green was reviewed and no QA/QC issues were found out of compliance. Method blank was ND at 30 ppm-c**. Laboratory Control Samples had 91 and 94% recovery with RPD of 2.4%. Spike amount was 3030 ppm-c. Sample results were 2100 ppm-c (51 G01) and 2300 ppm-c (52 G01) .

** ppm-c is parts per million equivalent carbon atoms. The analytical method separates each analyte, reduces the compound to CO₂ which is then oxidized to CH₄ and measured by a flame ionization detector. Hexane would produce six methane molecules (or carbon atoms), 1 ppm hexane is equivalent to 6 ppm-c hydrocarbon.

Hazardous Air Pollutants: Method TO-14A

The data package from Roger Green was reviewed and no QA/QC issues were found out of compliance. Method Blank was ND for all target analytes at low ppbv concentration. Laboratory Control Samples for 1,1-Dichloroethene, Methylene Chloride, Trichloroethene, Toluene and 1,1,2,2-Tetrachloroethane had recoveries of 99-109% (met limit of method) and RPD values of less than 2%.

Municipal Solid Waste Samples:

North Carolina State University. Sampling Dates: 6/6/2000 - 6/9/2000, 6/12/2000-6/15/2000, 6/20/2000-6/23/2000, 6/26/2000, 6/27/2000, 6/29/2000, 6/30/2000. Approximately 170 samples from varying depths and locations.

Roger Green provided an Excel Spreadsheet containing the results from NCSU. Approximately 170 samples (representing 26 separate horizontal sample locations) were analyzed for Organic Solids, Moisture Content, BMP, Cellulose, Lignin, and Hemicellulose. The spreadsheet contained average and RPD values.

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Organic Solids (QAPP Table 6-5):

The average Relative Percent Difference (RPD) was 2.04% well below the 25% objective. No result was above 10% RPD (maximum value was 9.6%)

Moisture Content (QAPP Table 6-6):

No replicate (precision estimates) data were found in the spreadsheet. Results from the Technical System Audit at NCSU indicated the precision objectives in Table 6-6 were unrealistic and should be removed.

Biochemical Methane Potential (QAPP Table 6-8):

The average RPD equaled 6.98%, well below the objective of 20%. Three of the 170 samples exceeded the 20% limit (29.82%, 30.34%, 41.67%). No matrix spike data were found in the spreadsheet. This should be reported for future validations.

OBSERVATION (8): NCSU should include the matrix spike results for BMP in future reports. The balance calibration records will be requested in the next data package for validation.

Non-Critical Measurements:

% Cellulose: The average RPD equaled 4.31%, only four samples (4/170) exceeded 20%.

%Lignin: The average RPD equaled 3.74%, only one sample (1/170) exceeded 20%.

%Hemicellulose: The average RPD equaled 4.52%, five samples (5/170) exceeded 20%.

Waste Management, Incorporated. GPS readings for Waste Settlement.

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Waste Settlement

Roger Green provided the settlement data in an Excel spreadsheet (monthly report). The spreadsheet contained data for July and October 2001, and January 2002. Five grid point QA/QC checks were included for each month. These grid points contain duplicate measurement of an individual location. Each location is characterized by the northing and easting coordinates carried to 1/100th. The maximum variation in replicate measurements in feet found in the data is 0.03, this corresponds to less than 1 cm. The criteria outlined in the QAPP is precision of ∇ 5cm. The data meet these precision requirements.

Waste Density (critical, field)

Measurement and calculation of waste density is based on GPS and contour information with the mass of waste put in the landfill (weight of each truck). Therefore, Waste Density measurement quality is based on the GPS data obtained for settlement and the weight calibration performed prior to truck weight measurements.

ADDITIONAL TECHNICAL COMMENT (2):Weight calibration data should be provided by WMI in the next data package.

**USEPA/Office of Research and Development
National Risk Management Research Laboratory**

INDEPENDENT DATA VALIDATION

Independent Data Validation of
Outer Loop Landfill Experimental Data

Performed by:

Neptune and Company

Date of Review: 11/27/2002

Experimental Data: 2nd - 3rd Quarters 2002

Data Packages Dates:
STL-Buffalo 10/01/2002
STL-Los Angeles 7/1/2002
STL-Los Angeles 7/23/2002

Task No: 39 TD8L
EPA Task Order Manager: Ann Vega

Introduction: Experimental data collection is in progress for the Landfill Bioreactor Studies at the Outer Loop Landfill (OLL), Louisville, Kentucky. These activities are guided by the Quality Assurance Project Plan, latest revision (Draft Final) dated July, 2002. The purpose of this task is to review and validate the data obtained in this project. To accomplish this, data were obtained from Roger Green, Waste Management Incorporated. The data packages included results from Severn Trent Services (STL Buffalo) for leachate sampling performed on September 16, 2002. This report of leachate samples included analysis for Volatile Organic Acids that was subcontracted to Microbial Insights. In addition, two data packages (STL Los Angeles) for gas analysis were received from Mr. Green. The gas sampling was performed on June 28, and June 13, 2002. No new MSW data is currently available. This validation process reviewed all critical and non-critical analyses included in the data packages and outlined in the QAPP Section 3.2, tables 3-4 to 3-6. The results of the data validation are outlined below and categorized by Matrix, importance of parameter in the project objectives and then by Analyte(s).

Data packages were evaluated (where appropriate) for Sample Identification (QAPP Section 4.7.1), Chain of Custody (QAPP Section 4.7.3), Correct Analytical Methods (QAPP Table 5.1), Container Preservation and Holding Times (QAPP Section 4.1, Table 4-1), Detection/Reporting Limits (QAPP Table 6-9) and Laboratory Quality Control for Critical Measurements, QAPP Section 6.4 (Tables 6-2 to 6-9).

Due to the limited amount of QC information provided in the standard data packages, STL-Buffalo was contacted to obtain raw data for the anions (including sulfate) and Volatile Organic (Metabolic) Acids analyses.

Overall the results from data validation indicate most laboratory analyses are in compliance with the QAPP quality control requirements. Only three Observations were noted with this report. However, as discussed in the previous data validation report, it is necessary to obtain matrix spike and/or duplicate analysis using the OLL matrix, especially for COD and BOD which are critical parameters. A discussion of reporting limits is included in the wet chemistry section. It is understood that analyzing a sample that contains high concentrations of analytes or other components can potentially compromise the integrity of an instrument. However, any steps that can be take to achieve detection status is extremely important for this project. The need to obtain results for all analytes so that each treatment cell can be compared should be emphasized to the laboratories.

Included in this report are the data for selected analytes received in this data validation project. There appears to be some evidence of differences in some of the analytes between the control cells and experimental cells, though direct comparison is not valid due to the offset in age between the cells.

Leachate Samples:

Severn Trent Services-Buffalo. Job # A02-9192, A02-9196. Samples Received 9/17/02.
Sample Date 9/16/02. Program Manager: Amy L. Haag.

Client Sample ID	Laboratory Sample ID
51A L01	A2919201
51B L01	A2919202
52A L01	A2919203
52B L01	A2919204
73A L01	A2919205
73B L01	A2919206
74A L01	A2919207
74B L01	A2919208

Table 1. Selected Analyte Results for Leachate.

Sample	Sulfate (mg/L)	BOD (mg/L)	COD (mg/L)	TDS (mg/L)	Temp. (EC)	Conductivity (UMHOS/CM)	VOA* (mg/L-C)
51A L01	120	204	2130	5800	32.9	14500	159
51B L01	41.8	97.3	1420	5020	32.9	14000	7
52A L01	32.2	106	1040	4520	34.2	8620	8
52B L01	80.6	480	1280	4260	30.0	9620	202
73A L01	127	156	675	2920	24.0	6760	0
73B L01	57.4	158	641	2640	24.1	5660	4
74A L01	100U	2340	6030	8500	33.7	15100	4328
74B L01	100U	3540	11500	10800	33.8	16600	8193

Sample	NH3 (mg/L)	TKN (mg/L)	Nitrite (mg/L)	Ortho-P (mg P/L)	Tot-P (mg P/L)	Cl- (mg/L)	K+ (mg/L)
51A L01	1170	836	0.19	3.0	4.1	1460	426
51B L01	1720	846	0.020U	6.4	17.8	1650	388
52A L01	1420	946	0.053	2.8	3.4	1110	340
52B L01	1240	438	0.020U	2.4	3.9	1010	307
73A L01	1160	371	0.078	1.4	2.5	569	237
73B L01	736	41.9	0.10	1.1	2.0	506	219
74A L01	2720	26.5	0.061	7.6	9.0	1400	533
74B L01	1420	100U	0.11	6.9	10.5	1360	565

* Volatile Organic Acids normalized on a carbon basis.

General:

The two sample coolers were received at 3EC with all samples in good condition. The Chain of Custody lists the bottle types but not preservative information as specified in Section 4.7.3 of the QAPP. The samples were grouped consistent with the expected preservatives (e.g. TKN, NH3, COD, total-P were in a single container consistent with sulfuric acid preservation) however neither preservative nor container type key is used, the numbers refer to number of bottles.

OBSERVATION (1): The Chain of Custody (COC) should include the preservatives as specified in the QAPP.

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Chemical Oxygen Demand (QAPP QC Activities Table 6-2): Method 410.4, STL SOP No. AWC-COD-44:

All eight samples were found above the RDL (Table 6-9). Samples 74A L01 and 74B L02 had very high COD concentrations (6030 and 11,500 mg/L respectively). No COD matrix spike was performed on the OLL samples, however a batch matrix spike was performed.

Biochemical Oxygen Demand (BOD₅, QAPP QC Activities Table 6-3): Method 405.1, STL SOP No. AWC-405.1-14:

All eight samples were analyzed for BOD. Samples 74A L01 and 74B L02 had very high BOD concentrations (2340 and 3540 mg/L respectively). Batch QC met the QAPP limits.

Non-Critical Measurements:

Volatile Organic Compounds, Method 8260:

All eight samples were analyzed for VOCs, the laboratory narrative indicated that no deviations from analytical protocol were encountered. The samples were diluted at a ratio of 1:10. This was done to prevent excessive foaming in the purge and trap instrument or due to high analyte concentrations. The batch blank and matrix spike samples met the criteria for surrogate and internal standard recoveries and lack of contamination. Holding times were also met.

Semi-Volatile Organic Compounds, Method 8270:

All eight samples were analyzed for SVOCs. Sample 73A L01 had one low internal standard (Perylene d-12) due to visible matrix interference (background, non-analyte compounds that produced the ion used to quantify d-12 Perylene), however no analytes were detected that use this internal standard for quantification. Sample 74B L01 had low recovery of surrogate 2-fluorophenol due to dilution. Dilution, due to the matrix effects or high analyte concentrations, was performed on seven of the samples. Holding times for extraction and analysis was achieved. Batch blanks and matrix spikes met the QAPP limits for recovery and lack of contamination.

RCRA Metals, Methods 6010B, 7470 (mercury):

All eight samples were analyzed for RCRA metals, no deviations from the protocol were encountered. Potassium analyses required dilution for all samples due to high

concentration. Preparation and analysis holding times were achieved. Batch blank and spike samples met the QAPP limits for lack of contamination and analyte recovery.

Wet Chemistry Analysis:

All eight samples were analyzed for the complete suite of wet chemistry analytes. Sample 52A L01 was originally analyzed for total dissolved solids within holding time but the result (1650 mg/L) was inconsistent with previous data. The sample was re-analyzed past the holding time but the result was in-line with previous data (4520 mg/L). Previous TDS results for this sample are provided in Table 2. Ammonia, chloride, ortho and total phosphate, and Total Kjeldahl Nitrogen (TKN) required dilutions in all samples due to matrix effects or high analyte concentrations. Sample 74B L01 was diluted by 1:1000 due to matrix effect for the TKN analysis resulting in a not detected (100 mg/L) status.

Table 2. Historical Total Dissolved Solids Results

Sample 52A L01 TDS	
Minimum:	4540
Maximum:	10400
Median:	8800
Mean:	8356
Standard Deviation:	2292

(Markwiese, et al, August 19, 2002)

The issue of high detection limits for sulfate in some samples has recently been under discussion between project participants. The exploratory data analysis report (Markwiese, et al) shows non-detect status for cells 51 and 52 at approximately 100 mg/L, previous reporting limits have been 10 mg/L. Raw data for this data package (September 16, 2002 sampling) was obtained from STL-Buffalo for the anion analytical method (300.0). Sulfate was detected in all samples above the RL of 10 mg/L with the exception of samples 74A L01 and 74B L02 which are reported as not-detected at 100 mg/L. All samples were run initially at 10% (1:10). All the sample analyses at a 10% dilution were inspected for the presence of large peaks. The chromatograms for the two samples that were reported as not detected (and therefore, not re-analyzed without dilution) do not appear significantly different from the other samples. STL-buffalo was contacted for information on why these two samples were only analyzed at 10% dilution. Amy Haag of STL-Buffalo reiterated that the matrix required diluting but she provided no further information as to why the analyst diluted only these two samples.

OBSERVATION (2). The reason for the dilution of samples 74A L01 and 74B L02 that resulted in non-detect status for sulfate should be fully resolved. It is unclear from the raw data why these samples could not be re-analyzed without dilution. One suggestion for preventing ND results would be to initially analyze all of the samples at a ratio of 1:5 instead of 1:10. It appears this dilution ratio would have resulted in detection of sulfate for these two samples without compromising the instrument.

**Microbial Insights, Rockford TN. Point of Contact: Michael Goodrich.
Sample Date 09/16/2002, Analysis Date 09/18/2002.**

Client Sample ID	Laboratory Sample ID
51A L01	A2919201
51B L01	A2919202
52A L01	A2919203
52B L01	A2919204
73A L01	A2919205
73B L01	A2919206
74A L01	A2919207
74B L01	A2919208

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Volatile Organic Acids, Microbial Insights, Point of Contact: Michael Goodrich. SOP No. VFA, Revision 1. (QAPP Table 6-4)

Raw QA/QC data were obtained for samples analyzed on September 18, 2002. The initial calibration and blank data met the requirements outlined in the QAPP, Table 6-4. The CCV and LCS standards are now run at 40 ppm and are within the method required limits. Matrix spike and matrix spike duplicate data met the project requirements for recovery, the relative percent difference was less than 20% for all six analytes. There appears to be a slight error in the reported value for propionic acid in sample 52B L01. The raw data indicates the correct value is 14 mg/L, the final STL-Buffalo report has a value of 16.9 mg/L. STL- Buffalo is reviewing the data to determine the correct value.

Sample reporting limits are 1 mg/L for all acids with the exception of pyruvic which is at 4 mg/L. Observation 2 is repeated in this report.

OBSERVATION (3): The project participants should decide if the reporting limits from Microbial Insights are sufficient and modify the QAPP as necessary.

Gas Samples:

Severn Trent Services- Los Angeles. STL Lot Number E2G020329 Amended and STL Lot Number E2F180191. Samples (E2G020329 Amended) Received 07/01/2002, Date Sampled: 06/28/2002. Samples (E2F180191) Received 06/17/2002, Date Sampled: 06/13/2002. Project Manager: Marisol Tabirara.

Four samples (E2F180191) were received June 17, 2002. Two additional gas samples (E2G020329) were received by STL-LA on July 1, 2002. The chain-of-custody and canister field data records indicate both sets of samples were received in good condition.

Table 3. Gas Analysis Results

Sample	CO ₂ (%)	CH ₄ (%)	N ₂ (%)	O ₂ (%)	NMOC (ppm-C)	Toluene* (ppb, TO-14)
51 G01	36	49	16	2.9	2000	13000
52 G01	20	25	49	11	1500	10000
73A G01	41	53	2.7	0.40	8300	46000
73A G02	41	53	1.8	ND (0.18)	11000	52000
73B G01	40	53	2.1	ND (0.18)	5300	51000
73B G02	46	55	ND (1.8)	ND (0.18)	5100	38000

Toluene concentration provided from TO-14 analysis as an indication of HAP levels .

Critical Measurements: (QAPP QA Objectives in Table 6-9)

Fixed Gases (Carbon Dioxide, Methane, Oxygen): Method 3C (QAPP Table 6-9).

Review of the data packages for Method 3C indicates the data met the QC requirements for accuracy and precision for the LCS and LCS duplicate. LCS samples had a recovery range of 106 to 111% for carbon dioxide (spike at 1%) and 106 and 112% for methane (spike at 0.0500%). Precision of the samples was well within the limit of 0-20%. The blanks were also found to be free from contamination.

Non-Critical Measurements:

Total Non-Methane Hydrocarbons: Method 25C Modified

Both data packages from Roger Green were reviewed and no QA/QC issues were found out of compliance. Method blank was ND at 30 ppm-c. Laboratory Control Samples had recoveries ranging from 108 to 100% recovery with the highest RPD of 2.3%. Spike amount was 600 ppm-c.

Hazardous Air Pollutants: Method TO-14A

Both data packages from Roger Green were reviewed and no QA/QC issues were found out of compliance. Method Blank was ND for all target analytes at low ppbv concentration. Laboratory Control Samples (50 ppb for 1,1-Dichloroethene, Methylene Chloride, Trichloroethene, Toluene and 1,1,2,2-Tetrachloroethane) had recoveries of 88-110% and RPD values of less than 6%, both QA indicators are within the limits specified in the QAPP.

**USEPA/Office of Research and Development
National Risk Management Research Laboratory**

Independent Data Validation

**Independent Data Validation of
Outer Loop Landfill Experimental Data**

**Performed by:
David A. Gratson
Neptune and Company**

Date of Report: 8/21/2003

Experimental Data: 3rd Quarter 2002, 1st & 2nd Quarters 2003

**Task No: 05 WO Seq. No. 07b
EPA Task Order Manager: Scott Jacobs**

Introduction: Data collection is in progress for the Landfill Bioreactor Studies at the Outer Loop Landfill, Louisville, Kentucky. These activities are guided by the Quality Assurance Project Plan, latest revision (Draft Final) dated May 6, 2003. The purpose of this task is to review and validate the data obtained in this project. To accomplish this, data were obtained from Roger Green, Waste Management Incorporated and from Morton Barlaz, NCSU during a Technical Systems Audit at his laboratory in August, 2003. The data packages from Roger Green included results from Severn Trent Laboratory - Buffalo (STL-Buffalo) for leachate and Severn Trent Laboratory- Los Angeles (STL-LA) for gas samples. The STL-Buffalo reports included analysis for Volatile Organic Acids that was subcontracted to Microbial Insights. This validation process reviewed all critical parameters and a few of the non-critical analyses included in the data packages and outlined in the QAPP Section 3.2, tables 3-4 to 3-6. The results of the data validation are outlined below and categorized by medium.

Data packages were evaluated (where appropriate) for Sample Identification (QAPP Section 4.7.1), Chain of Custody (QAPP Section 4.7.3), Correct Analytical Methods (QAPP Table 5.1), Container Preservation and Holding Times (Table 4-1), Detection/Reporting Limits (QAPP Table 6-9) and Laboratory Quality Control for Critical Measurements, QAPP Section 6.4 (Tables 6-2 to 6-9).

Limited amount of QC information is provided in the standard (Level II) data packages, however matrix and laboratory control spikes were included in the leachate data packages and QC requirements for the MSW data were reviewed in a recently completed audit.

Overall the results from data validation indicate most laboratory analyses are in compliance with the QAPP quality control requirements. **ALL CRITICAL DATA REVIEWED CAN BE USED** in project reports. Some data has been qualified due to quality control issues identified and should be used with caution. The use of the data is context specific. For example, Volatile Organic Acids with low spike recoveries may indicate negative bias. However, one might assume all samples had similar bias and are thus comparable. More caution may be in order when comparing samples for BOD where one or more were analyzed out of holding times.

Leachate Samples: STL-Buffalo

Critical Leachate Parameters: BOD, COD, Volatile Organic Acids (Microbial Insights). Some of the files also contained field data for pH (critical) and conductivity.

Eleven Acrobat (pdf) files were obtained from STL-Buffalo with results for leachate analysis. The files were associated with samples collected from November 2002 to July, 2003. Acrobat Files: A02-A447, A02-B373, A02-C503, A03-0709, A03-1405, A03-2498, A03-3377, A03-5054, A03-5431, A03-5975, A03-7170.

Excel spreadsheets (with the same name as the Acrobat files) with the summary data were also received and validated for data qualifiers.

QA Evaluation:

File A02-A447, samples 51A, 51B, 52A, 52B, 73A, 73B, 74A, 74B, sampled 10/21/02: The pH check (using a 7.0 buffer solution) reading was 7.28. The QC requirements for verification of pH are 7.00 ± 0.1 units (Table 6-1-1). These data are qualified as potentially biased high (J+) due to the results of this QC check. Butyric acid had low recovery (60.7 and 74.7%) in the matrix spike and duplicate. All samples were ND for butyric acid (1 mg/L limit), there is potential for false negative results due to this low recovery.

File A02-B373, samples 51A, 51B, 52A, 52B, 73A, 73B, 74A, 74B, sampled 11/14/2002: One set of samples (51A L01, 51B L01, 52A L01, 52B L01) was not preserved for COD when received (within 24 hours, good condition), the laboratory added sulfuric acid to achieve the required pH.

File A02-C503, samples 51A, 51B, 52A, 52B, 73A, 73B, 74A, 74B, sampled 12/16/2002: Acetic and propionic acid (Volatile Organic Acids) had very high matrix spike recoveries (300-400%). All samples (especially 74A L01, 74B L01) are qualified as potentially biased high (J+).

File A03-0709, samples 51A, 51B, 52A, 52B, 73A, 74A, 74B, sampled 1/22/03: 74A L01 BOD results were qualified by the laboratory as estimated (E) because the holding time was out of compliance (the initial dilution resulted in oxygen concentration that did not meet the method criteria). These BOD results should be used with caution.

File A03-1405, samples 51A, 51B, 52A, 52B, 73A, 73B, 74A, 74B, sampled 2/12/2003: All samples for COD/ammonia/total phosphate were received unpreserved. The laboratory added sulfuric acid to achieve the desired pH (within 24 hours of sampling). The initial BOD analysis for sample 73B L01 was depleted in oxygen; the reanalysis was performed out of holding times. Both results were reported, the first is qualified as estimated (72.0E), the second results was 74.7 mg/L. These BOD results should be used with caution.

File A03-3377, samples 51A, 51B, 52A, 52B, 73A, 73B, 74A, 74B, sampled 4/10/03: Samples 74A L01 and 74B L01 were received unpreserved. The laboratory added sulfuric acid to achieve the desired pH.

File A03-5054, samples 51A, 52A, 52B, 73A, 73B, 74A, 74B, sampled 5/23/2003: The initial BOD analysis for sample 74A L01 was depleted in oxygen; the reanalysis was out of holding times. Both results were reported (without qualification): ND (reporting limit 1800), reanalysis 216 mg/L. The reanalysis result should be qualified as estimated (E) and used with caution.

File A03-5431, samples 51A, 51B, 52A, 52B, 73A, 73B, sampled 6/5/2003: The pH check (using a 7.0 buffer solution) reading was 7.13. The samples are qualified as potentially biased high (J+) due to the results of this QC check. The RPD results for propionic and butyric acid are greater than the 20% limit; the LCS meet the QC requirements for all acids. Matrix spike recovery for pyruvic acid is low (56.8%, 54.7%). All samples were ND for pyruvic acid (4 mg/L limit), there is potential for false negative results due to this low recovery.

File A03-5975, samples 74A and 74B, sampled 7/14/2003: The matrix spike recovery for pyruvic acid was 51.8 and 52.0%. Pyruvic acid is ND in both samples, there is potential for false negative due to this low recovery.

File A03-7170, samples 51A, 51B, 52A, 52B, 73A, 73B, 74A, 74B, sampled 7/25/2003: The pH check (using a 7.0 buffer solution) reading was 7.16. The samples are qualified as potentially biased high (J+) due to the results of this QC check.

A number of sample reports indicated interference with the non-critical parameter nitrite. These data should be used with caution since bias is likely. All results with an estimated (E) qualifier from the laboratory (e.g. BOD) should be used with caution. BOD, in particular, is susceptible to degradation and negative bias if analysis is not started within 24 hours.

MSW Samples: NCSU

Critical MSW Parameters: Moisture, Organic (Volatile) Solids, BMP.
Excel Files: BMP_1_08_04_03, BMP_2_08_04_03, Lablogbook, LablandfillsMoistures, OL#3 data 081903, Volatiles-OL Set 3.

QA Evaluation:

Moisture and Organic (Volatile) Solids data was evaluated by reviewing the excel spreadsheets provided. The parameters are obtained by weighing samples before and after drying (65°C) or oxidation (550°C). Data validation is performed by ensuring the spreadsheets are correctly calculating the parameter using the entered data. This data is entered into the spreadsheet by the analysts and spot checked by peers, and/or Dr. Barlaz at NCSU. No problems were identified with the Moisture or Organic Solids data.

BMP data was evaluated from two spreadsheets that contain MSW samples from the November, 2002 sampling period. The spreadsheets contain daily calibration information along with the calculations for methane (corrected for STP and inoculum blanks), nitrogen, carbon dioxide, and oxygen. The precision (RSD/CV) is calculated for each set of triplicate samples (each sample undergoes the complete incubation and gas analysis process) and evaluated against the 20% criterion. Samples that exceed this criterion are re-analyzed (complete process) until the metric is achieved. A few minor mistakes in

formulas within the spreadsheet were noted and discussed with Dr. Barlaz. These errors have been corrected and a consistent model is now used to calculate methane. There are six sets of data in which the lowest calibration standard (10% methane) was unavailable. The SOP for calibration requires at least three calibration levels. However, after evaluating the calibration data I believe these data are valid. The slope of the calibration model for these six sets is very similar to that obtained using a full calibration. There is 3.1% difference in the average slope between the calibrations with three levels versus the calibration with two levels. This potential error level is within the precision of this analytical method. However, all future analyses should follow the method that requires at least three calibration levels*.

Gas Samples: STL-LA

Critical Parameters: Methane, Carbon Dioxide, Oxygen via Summa Canisters.
Acrobat Files: E2K250218, E12300222, E2L300223, E3D160263, E3F100284, M2C260265, E2F180191, E2G026329, M1C200280, M1L200214. Excel Files with the same names were also obtained, these contain summary data.

QA Evaluation:

The only quality issue noted for the critical parameters for the gas samples is holding times. A number of samples were analyzed between 7 and 14 days after collection. The QAPP specifies a holding time of 7 days (Table 4-1). There is no reason to believe the composition of the gas samples (methane, carbon dioxide, and oxygen) are compromised when analysis is performed within 14 days of collection (using Summa Canisters). For reference, Method 3C does not list a holding time and Method TO-14A has a 30 day holding time. All other QA/QC issues met the method and/or QAPP specifications.

* While evaluating the methane calibration data received with the BMP results two issues arose that could potentially improve the current method. These ideas came out of a meeting held with David Gratson and Vicki Lancaster of Neptune and Company, Inc. and Morton Barlaz. The current calibration method is acceptable; however improved calibration precision may be achieved through the use of a weighted least squares regression model. The idea of using a single calibration slope that is acquired on a single day, then verified during daily calibrations is also being considered. NCSU is currently performing additional calibration to test these ideas.

APPENDIX D

STATISTICAL ANALYSIS

NEPTUNE AND COMPANY, INC.
2031 Kerr Gulch Road
Evergreen, CO 80439
Phone: 720.746.1803
Fax: 720.746.1605
pblack@.neptuneinc.org

MEMORANDUM

From: Jim Markwiese, Paul Black, Tom Stockton, Doug Bronson, Andrew Schuh
To: Scott Jacobs, Ann Vega
Date: 24 September 2003

Subject: Statistical Analysis for Bioreactor Study

Some preliminary data analyses, replicate analyses, and trend analyses are presented in the attached document for the data collected from the bioreactor experiments for WMI. Data have been provided by WMI for leachate for the 3 units, FLB, AALB, and control, and for solids, field gas, and landfill gas for the 2 units, FLB, and control (see attachment on data sources). The data are limited, reflecting the early stages of data collection for this 5-year project. The statistical analyses follow. Interpretation of the plots should consider the following notes:

1. The time plots presented below have different y-axis scales, so some care should be taken during interpretation. The x-axis scales are the same for each set of plots.
2. Lines drawn on the time plots are smoothed regression lines (using the LOESS function) when there are sufficient data (including detections).

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I. SUMMARY

II. BIOREACTOR CELL TIMELINES

This plots give the reader some sense of the date of activity of the landfills as well as the dates for which data is available for them.

III. SUMMARY STATISTICS FOR LEACHATE AND GAS DATA

These are the basic statistics for the field gas and leachate including mean, median, quantiles, min, max, and standard deviation for data subset out by cell and replicate (A/B).

IV. LEACHATE TIME PLOTS

This is a good place to start for the leachate data as it gives the reader a good overall feeling for the behavior of the data. Rigorous statistical analysis of trends and replicates is left to sections VI. and IX.

V. LEACHATE REPLICATE ANALYSIS

This section investigates the differences between the replicates of each of the cells (FLB cell 5.1, FLB cell 5.2, Control cell 7.3, and 7.4). Also included is an analysis of some alternative replicate configurations based upon “after the fact” knowledge of the geometry and location of the cells and their replicates. Essentially, different polynomial models are fit to the data, a best model form chosen, and then the parameters are tested for significant differences.

VI. FIELD GAS TIME PLOTS

This section includes time plots of the field gas data and is a good place to start when trying to understand this data.

VII. FIELD GAS BOX PLOTS

This section contains boxplots of the field gas data with the Date variable being “collapsed”. Essentially these are additional diagnostic plots that provides a visual picture of overall concentrations.

VIII. TREND TESTS

This section tracks our attempts to detect statistically significant trends in the leachate data. It also includes some slope estimates which may be useful when a significant trend is evident.

IX. LEVELPLOT OF SETTLING HEIGHT CHANGE

This is a simple “contour” style LOESS plot of the settling height change. No rigorous statistical tests are performed on this data and this plot is included for qualitative purposes only.

X. DATA SUMMARY

This is a summary of the data we have received up until this point in time.

Summary

At this point in the CRADA there is a major difficulty in comparing the treatment cells (FLB and AALB) to the control cells due to several confounding factors. As time progresses and more data become available, some of these confounding factors (e.g., non-overlapping aged waste between cells) are expected to become less of a hindrance to statistical analysis. For now, however, if a difference is found between types of cells, it is challenging to determine if the difference is due to treatment or age. Confounding factors that could have an effect on critical parameters are:

- geometry of cell
- amount of waste disposed in cell
- type of waste disposed in cell
- time of waste disposal in cell

As further data are collected, these factors can be addressed.

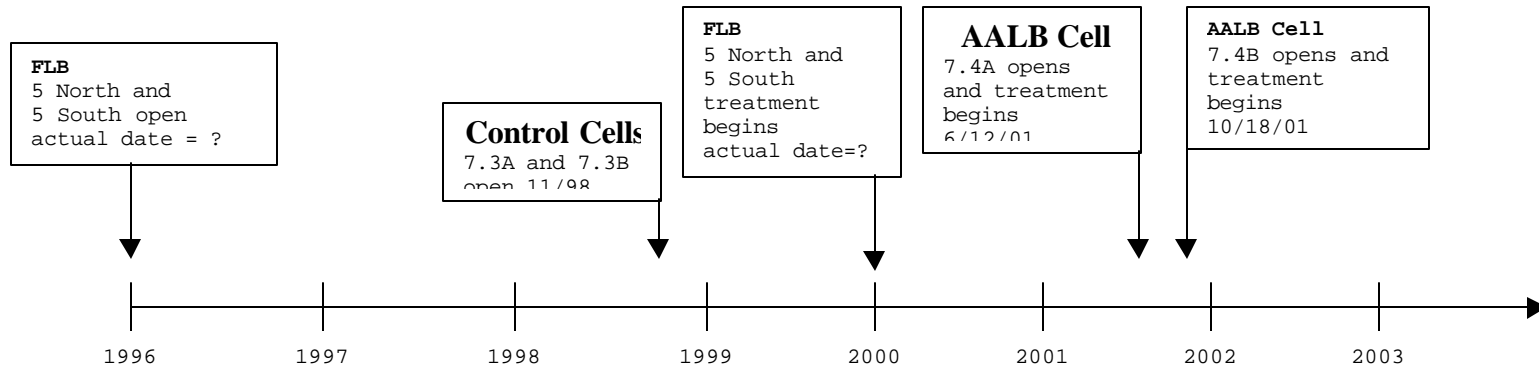
Because of the difficulties above, the main focus of this document will be on: exploratory data analysis of critical leachate and field gas parameter along with the comparison of the A and B pairs of cells. The comparison is important because the pairs are intended to be replicates, but have been subjected to different conditions. Other topics include trend analysis of critical parameters and initial exploratory data analysis of the solids and settling data.

Leachate data has been collected quarterly, so sample sizes are approximately 20 within each cell. Also, data values are highly variable and there are many confounding variables. These factors make modeling or comparing cells very difficult. Still, visual inspection of LOESS smooths of the time plots and analysis of covariance F-tests demonstrate that the A and B pairs within cells are similar.

Field Gas data has been collected weekly and values are far less variable than the leachate data. Time plots indicate that concentrations in control and FLB cell 5.1 are quite similar. Concentrations are flat and linear. On the contrary, concentrations in FLB cell 5.2 follow a definite non-linear trend. Time plots and box-plots indicate concentrations in FLB cells are higher in variability than in the control cells.

BIOREACTOR CELL TIMELINES

CELL AGE AND DATA TIMELINE



leachate.txt (approx. monthly collection)

FLB	6/01	●	●	4/03
AALB	12/01	●	●	4/03
CTRL	6/01	●	●	4/03

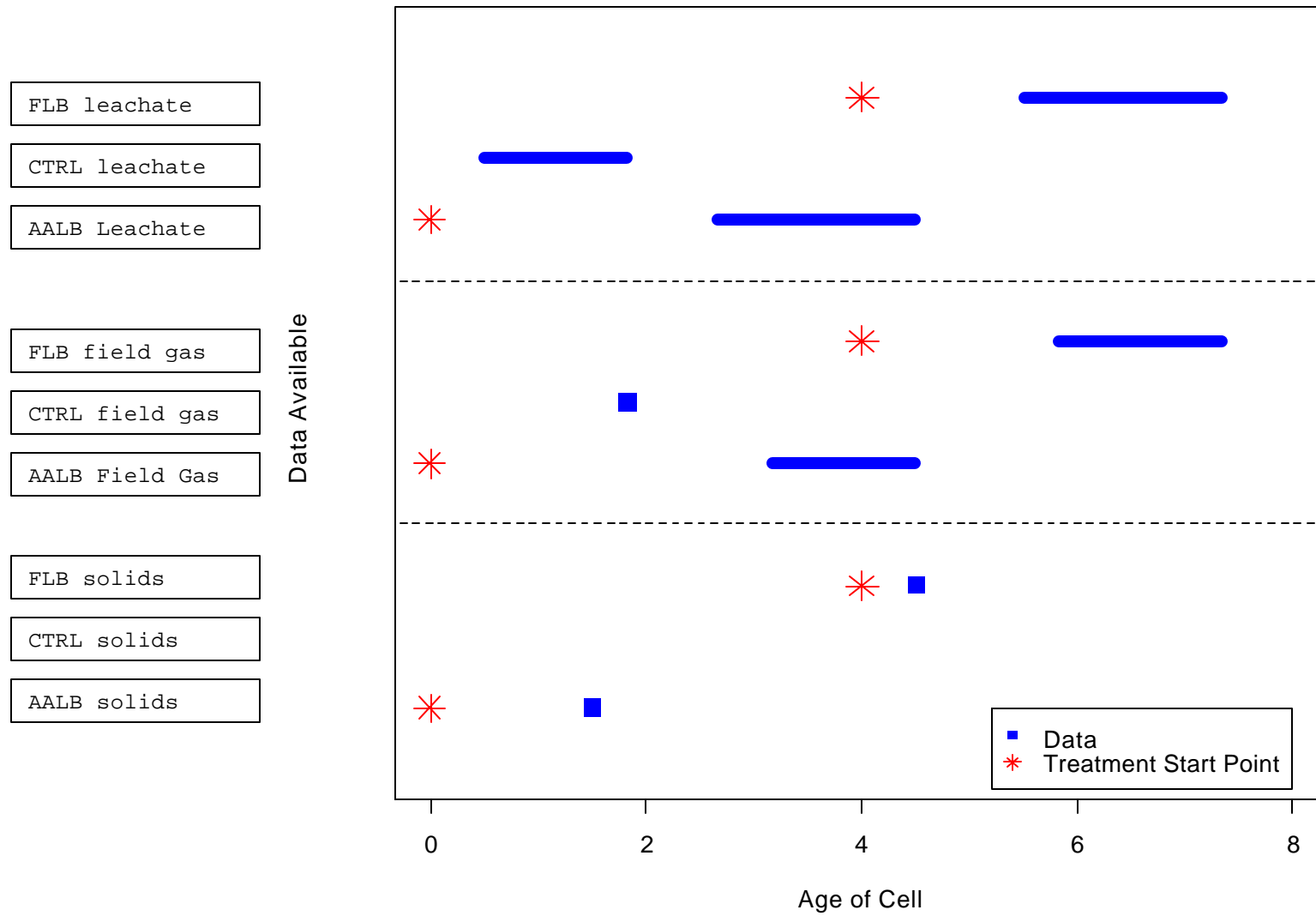
field.gas.txt (approx. weekly collection)

FLB	11/16/01	●	●	4/11/03
AALB			●	4/11/03
CTRL	1/10/02	●	●	4/11/03

solids.txt (annual collection)

FLB	●	6/00
AALB	none	
CTRL	●	6/00

Data Available versus Age of Cell



**SUMMARY STATISTICS
FOR LEACHATE AND GAS FIELD DATA
(data thru Spring 2003)**

LEACHATE

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Acetic Acid	FLB 5.1	A	18	1.0	1.6	3.3	163.0	5.0	2350	552.31
	FLB 5.1	B	18	1.0	2.1	3.4	10.9	7.0	80	19.24
	FLB 5.2	A	18	1.0	2.5	3.8	5.6	8.0	20	4.89
	FLB 5.2	B	18	1.0	1.6	2.3	150.1	22.3	2340	548.46
	Control 7.3	A	18	1.0	1.0	1.9	24.1	2.5	389	91.14
	Control 7.3	B	17	1.0	1.9	11.0	109.3	44.0	1010	263.81
	AALB 7.4	A	17	1.0	10.0	243.0	484.2	1010.0	1650	554.73
	AALB 7.4	B	17	2.9	23.0	151.0	582.1	539.0	2580	845.87

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Ammonia (As N, MG/L)	FLB 5.1	A	21	551	831.0	1070.0	2444.5	1590.0	19200	4410.3
	FLB 5.1	B	21	468	707.0	976.0	1168.8	1410.0	3100	678.7
	FLB 5.2	A	20	291	865.0	1325.0	1278.1	1570.0	2580	551.6
	FLB 5.2	B	21	432	723.0	877.0	1290.5	1250.0	7010	1392.5
	Control 7.3	A	20	67.1	108.5	298.0	459.8	585.8	1420	432.3
	Control 7.3	B	19	48.6	114.5	239.0	376.1	409.5	1410	406.1
	AALB 7.4	A	17	162	545.0	741.0	922.1	942.0	2720	653.4
	AALB 7.4	B	17	97.3	650.0	1040.0	920.7	1320.0	1540	462.8

	cell	id	n	min	Q1	median	mean	Q3	max	sd
BOD (MG/L)	FLB 5.1	A	22	32.9	61.8	95.5	189.0	216.8	1060	228.7
	FLB 5.1	B	23	21.7	74.3	119.0	165.4	228.0	629	145.2
	FLB 5.2	A	20	19.8	52.2	127.0	138.0	181.3	414	100.1
	FLB 5.2	B	21	24.9	58.7	84.5	156.0	159.0	783	185.7
	Control 7.3	A	20	14.6	34.0	49.9	155.6	99.0	1820	395.4
	Control 7.3	B	21	9.2	45.5	158.0	1784.0	198.0	31400	6805.0
	AALB 7.4	A	20	20.0	182.3	469.0	1967.0	2378.0	15000	3427.1
	AALB 7.4	B	18	142.0	517.8	2085.0	6233.0	6280.0	54400	12546.6

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Chloride (MG/L)	FLB 5.1	A	9	818	1460.0	1850.0	1694.2	2060.0	2250	467.2
	FLB 5.1	B	8	955	1570.0	2485.0	2154.4	2732.5	2840	736.0
	FLB 5.2	A	7	1110	1355.0	1920.0	2027.1	2700.0	3050	794.4
	FLB 5.2	B	9	10	860.0	1180.0	1072.1	1390.0	1930	547.2
	FLB 5.1	A	9	818	1460.0	1850.0	1694.2	2060.0	2250	467.2
	FLB 5.1	B	8	955	1570.0	2485.0	2154.4	2732.5	2840	736.0
	FLB 5.2	A	7	1110	1355.0	1920.0	2027.1	2700.0	3050	794.4
	FLB 5.2	B	9	10	860.0	1180.0	1072.1	1390.0	1930	547.2

COD (MG/ L)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	882.0	1790	1890	1848.0	1970.0	2620	449.1
	FLB 5.1	B	21	1000.0	1250	1560	1659.0	1960.0	2530	486.8
	FLB 5.2	A	20	10.0	1035	1595	1638.0	2140.0	3840	1054.1
	FLB 5.2	B	21	114.0	1200	1350	1366.0	1440.0	3560	640.7
	Control 7.3	A	20	114.0	259	435	667.2	687.3	3170	721.0
	Control 7.3	B	19	60.3	235	618	963.8	992.0	5720	1297.2
	AALB 7.4	A	17	916.0	1580	2290	5282.0	6030.0	30900	7488.5
	AALB 7.4	B	17	1840.0	2250	4220	7222.0	9330.0	26000	7039.3

Nitrite (As N, MG/L)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	0.02	0.03	0.06	0.08	0.10	0.28	0.07
	FLB 5.1	B	20	0.02	0.02	0.07	0.12	0.12	0.71	0.17
	FLB 5.2	A	19	0.02	0.02	0.07	0.08	0.11	0.38	0.09
	FLB 5.2	B	21	0.02	0.02	0.03	0.06	0.08	0.24	0.06
	Control 7.3	A	20	0.02	0.02	0.02	0.06	0.09	0.28	0.07
	Control 7.3	B	19	0.02	0.02	0.06	0.19	0.10	2.00	0.45
	AALB 7.4	A	17	0.05	0.12	0.19	0.24	0.32	0.65	0.18
	AALB 7.4	B	17	0.09	0.12	0.17	1.30	0.44	10.70	2.78

Nitrogen (Nitrate, MG/L)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	0.02	0.02	0.04	0.06	0.10	0.13	0.04
	FLB 5.1	B	20	0.02	0.02	0.02	0.09	0.10	0.57	0.13
	FLB 5.2	A	19	0.02	0.02	0.02	0.07	0.09	0.28	0.07
	FLB 5.2	B	21	0.02	0.02	0.02	0.04	0.05	0.20	0.05
	Control 7.3	A	20	0.02	0.02	0.02	0.05	0.03	0.20	0.06
	Control 7.3	B	19	0.02	0.02	0.03	0.05	0.05	0.26	0.06
	AALB 7.4	A	17	0.02	0.02	0.10	0.22	0.19	1.70	0.40
	AALB 7.4	B	17	0.02	0.10	0.18	2.31	1.00	26.50	6.38

PH (S.U.)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	6.92	7.14	7.22	7.222	7.34	7.56	0.15513
	FLB 5.1	B	21	6.95	7.17	7.30	7.255	7.36	7.51	0.16046
	FLB 5.2	A	20	6.65	7.15	7.28	7.244	7.36	7.62	0.20671
	FLB 5.2	B	21	6.84	7.10	7.16	7.161	7.28	7.33	0.13203
	Control 7.3	A	20	6.38	6.55	6.88	6.834	7.05	7.31	0.29601
	Control 7.3	B	19	6.14	6.42	6.85	6.752	7.05	7.20	0.33671
	AALB 7.4	A	17	6.31	7.01	7.13	7.072	7.20	7.40	0.27369
	AALB 7.4	B	17	5.89	6.64	7.11	6.964	7.37	7.57	0.50964

Phosphate, Ortho (MG P/L)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	1.6	2.5	2.7	2.9	3.4	4.6	0.8
	FLB 5.1	B	20	0.98	1.6	2.3	2.6	3.2	6.4	1.3
	FLB 5.2	A	19	1.4	2.9	3.4	4.0	4.7	7.8	1.9
	FLB 5.2	B	21	0.54	1.2	1.9	2.0	2.3	6.8	1.3
	Control 7.3	A	20	0.08	0.7	0.9	1.1	1.4	3.4	0.8
	Control 7.3	B	19	0.27	0.6	0.8	1.1	1.2	4.8	1.0
	AALB 7.4	A	17	0.8	1.7	1.9	3.4	3.6	15.4	3.5
	AALB 7.4	B	17	1.2	2.1	3.4	3.7	4.7	8.2	2.0

Phosphorous, Total (MG P/L)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	0.77	2.4	2.7	2.9	3.5	5.3	1.2
	FLB 5.1	B	21	0.12	1.6	2.0	3.0	2.9	17.8	3.7
	FLB 5.2	A	20	1.3	3.1	4.4	4.7	6.8	9.9	2.4
	FLB 5.2	B	21	1	1.5	2.3	3.2	3.2	14.2	2.9
	Control 7.3	A	20	0.11	0.7	0.9	1.5	1.9	5.3	1.3
	Control 7.3	B	19	0.11	0.8	1.4	1.8	2.3	5.6	1.5
	AALB 7.4	A	17	0.92	2.8	3.5	5.4	8.3	21.6	5.1
	AALB 7.4	B	17	0.33	1.7	3.1	3.8	4.2	10.5	3.2

Temperat ure (° C)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	23.0	26.8	30.5	29.58	31.4	34.6	3.4048
	FLB 5.1	B	21	23.5	26.1	27.0	27.91	29.7	32.9	2.6107
	FLB 5.2	A	20	19.0	27.9	30.3	29.28	31.9	35.3	4.6443
	FLB 5.2	B	20	21.1	24.5	25.7	25.82	27.0	31.1	2.5980
	Control 7.3	A	20	9.5	11.9	15.1	16.24	19.1	25.3	4.9550
	Control 7.3	B	19	6.8	12.3	18.2	16.99	20.1	25.1	5.2618
	AALB 7.4	A	17	19.8	24.8	30.6	29.08	33.0	34.7	4.6699
	AALB 7.4	B	17	15.3	21.9	26.3	24.96	28.6	33.8	5.4191

Total Kjeldahl Nitrogen (TKN)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	9	189	612.0	955.0	812.7	1040.0	1160	348.8
	FLB 5.1	B	9	362	526.0	1030.0	882.8	1200.0	1250	370.6
	FLB 5.2	A	8	445	643.3	1088.0	1032.0	1355.0	1580	432.2
	FLB 5.2	B	9	89.2	394.0	505.0	585.2	1010.0	1040	365.6
	Control 7.3	A	8	91.9	123.8	179.0	194.1	236.8	371	94.1
	Control 7.3	B	8	12.6	36.5	55.3	94.7	83.0	390	123.1
	AALB 7.4	A	5	26.5	118.0	260.0	246.7	395.0	434	174.9
	AALB 7.4	B	5	100	169.0	171.0	298.6	332.0	721	251.0

FIELD GAS

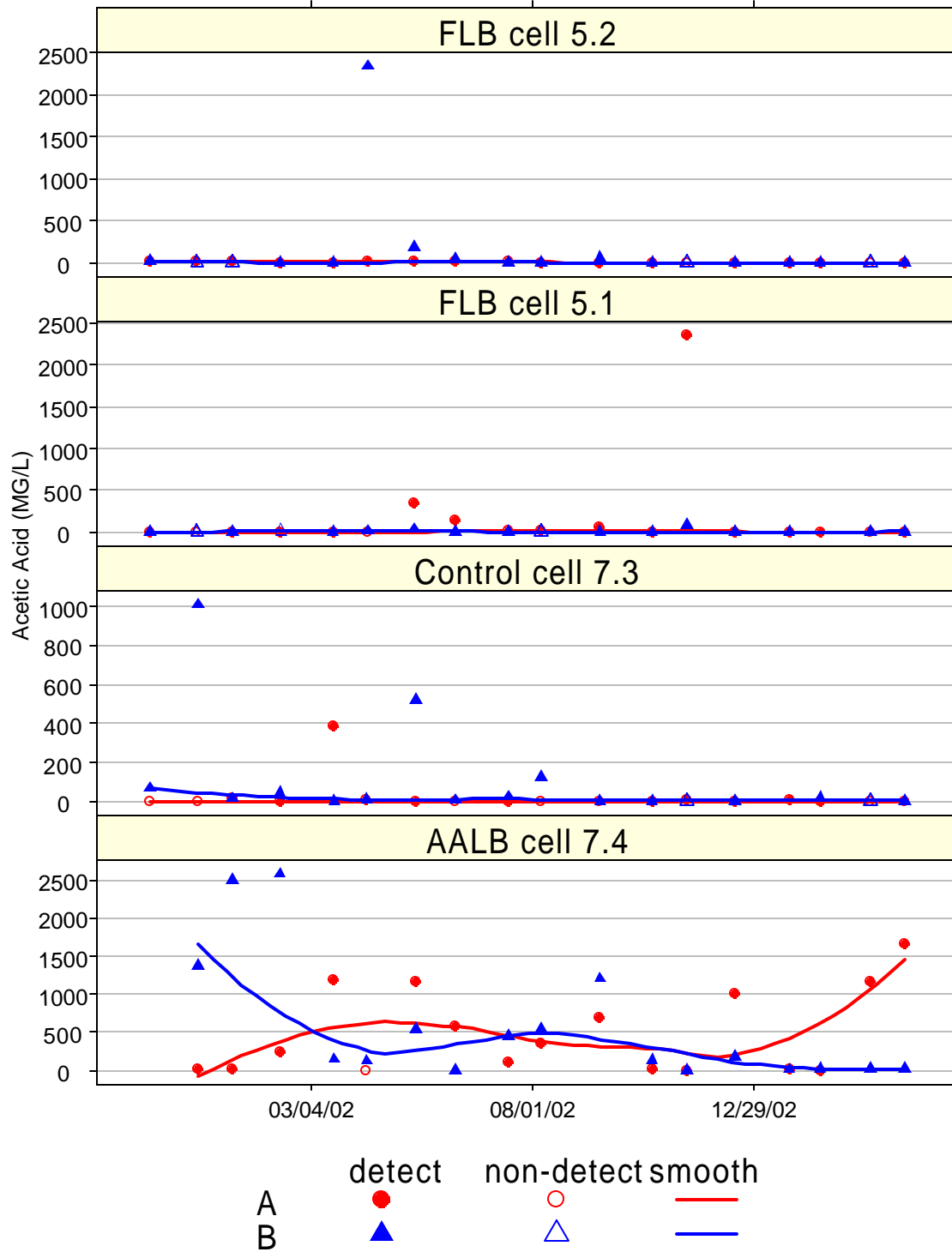
	cell	id	n	min	Q1	median	mean	Q3	max	sd
CH4	FLB 5.1		207	3.9	47.0	52.2	49.43	55.3	99.9	11.2770
	FLB 5.2		208	3.9	26.3	39. 5	38.04	53.9	61.9	16.6666
	Control 7.3	A	334	44.4	56.7	57.4	58.32	58.6	69.1	3.3828
	Control 7.3	B	353	51.0	56.4	57.6	57.27	58.4	62.7	1.9394
	AALB 7.4	A	4	54.5	54.5	54.7	54.65	54.8	54.8	0.1732
	AALB 7.4	B	3	54.7	54.8	54.8	54.80	54.9	54.9	0.1000

	cell	id	n	min	Q1	median	mean	Q3	max	sd
CO2	FLB 5.1		207	3.2	33.0	36.8	34.79	38.7	45.7	7.3830
	FLB 5.2		208	3.1	19.9	29. 5	28.16	39.4	46.8	11.9248
	Control 7.3	A	334	29.2	41.7	42.5	42.19	43.1	45.2	1.6187
	Control 7.3	B	353	36.6	40.2	41.3	41.11	42.0	44.7	1.2481
	AALB 7.4	A	4	41.7	41.7	41.7	41.73	41.7	41.8	0.0500
	AALB 7.4	B	3	42.2	42.2	42.2	42.23	42.3	42.3	0.0577

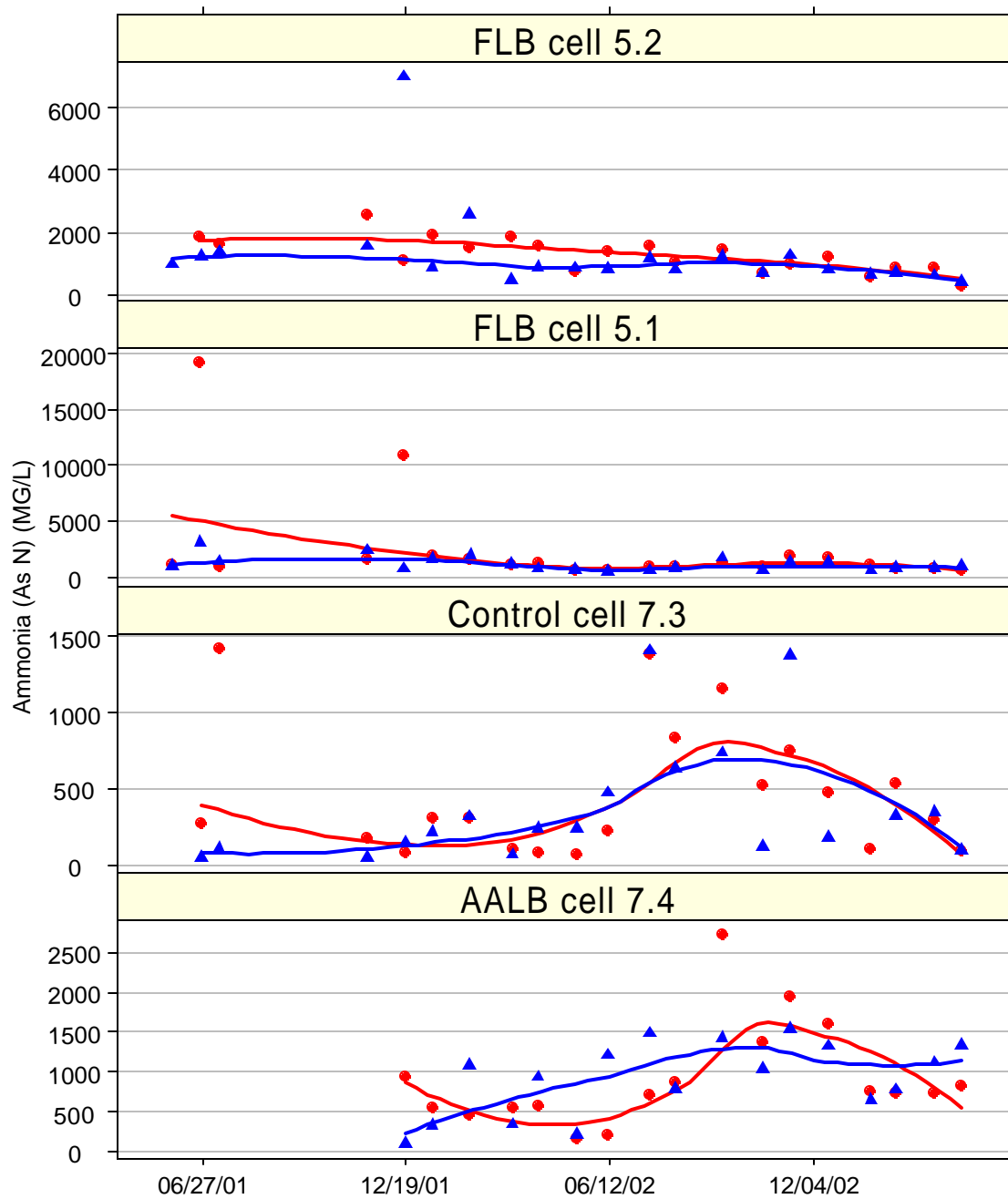
	cell	id	n	min	Q1	median	mean	Q3	max	sd
O2	FLB 5.1		207	0.1	1.3	2.1	3.436	4.3	18.7	3.5951
	FLB 5.2		208	0.0	1.3	6.6	6.641	10.0	18.9	5.4264
	Control 7.3	A	334	0.0	0.0	0.0	0.273	0.2	12.9	0.9682
	Control 7.3	B	353	0.0	0.0	0.0	0.331	0.4	8.4	0.7174
	AALB 7.4	A	4	0.7	0.7	0.9	0.850	1.0	1.0	0.1732
	AALB 7.4	B	3	0.8	0.9	0.9	0.867	0.9	0.9	0.0577

LEACHATE TIME PLOTS

Acetic Acid

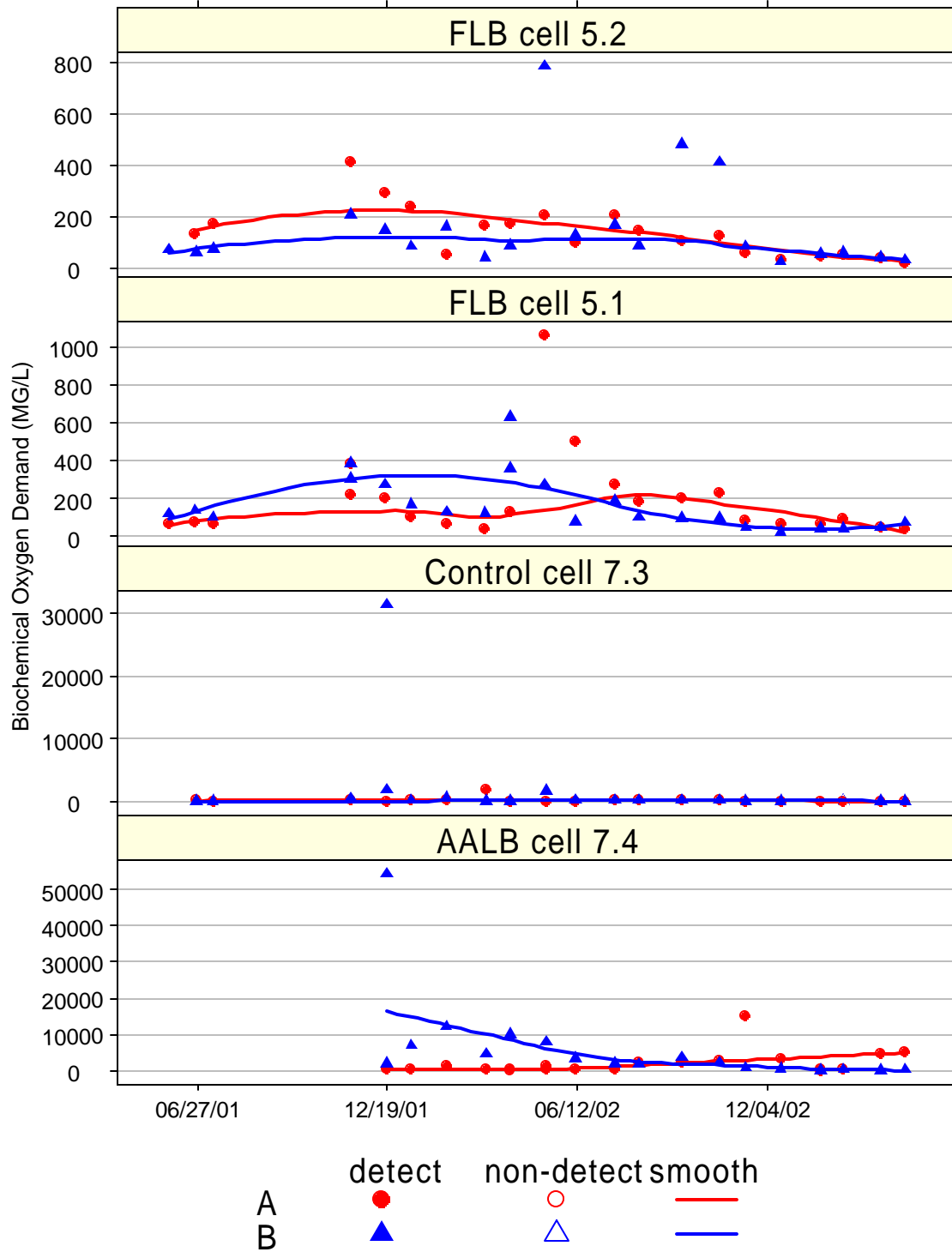


Ammonia (as N)

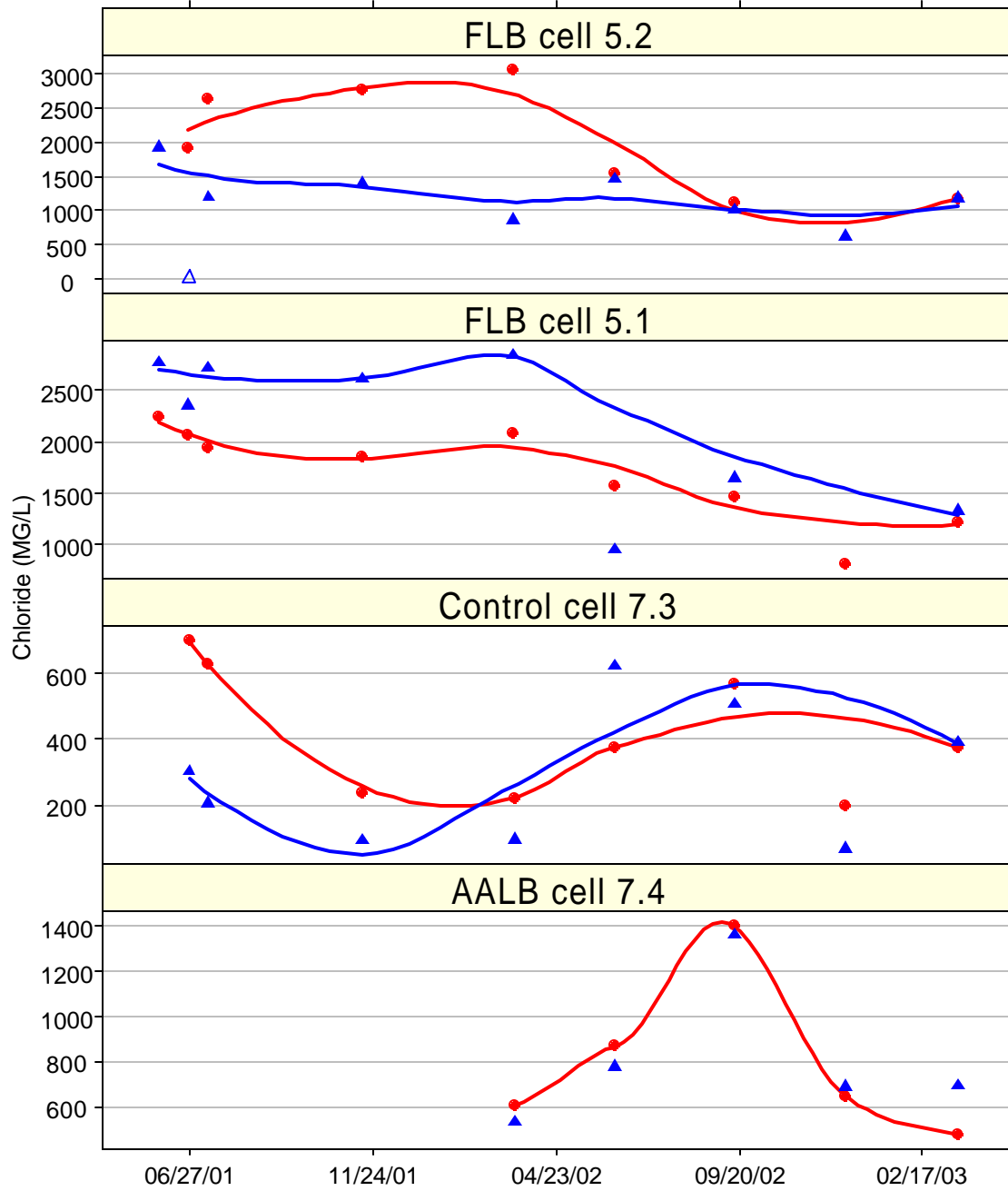


A detect non-detect smooth
 B ● ▲ ○ △ — —

Biochemical Oxygen Demand (BOD)

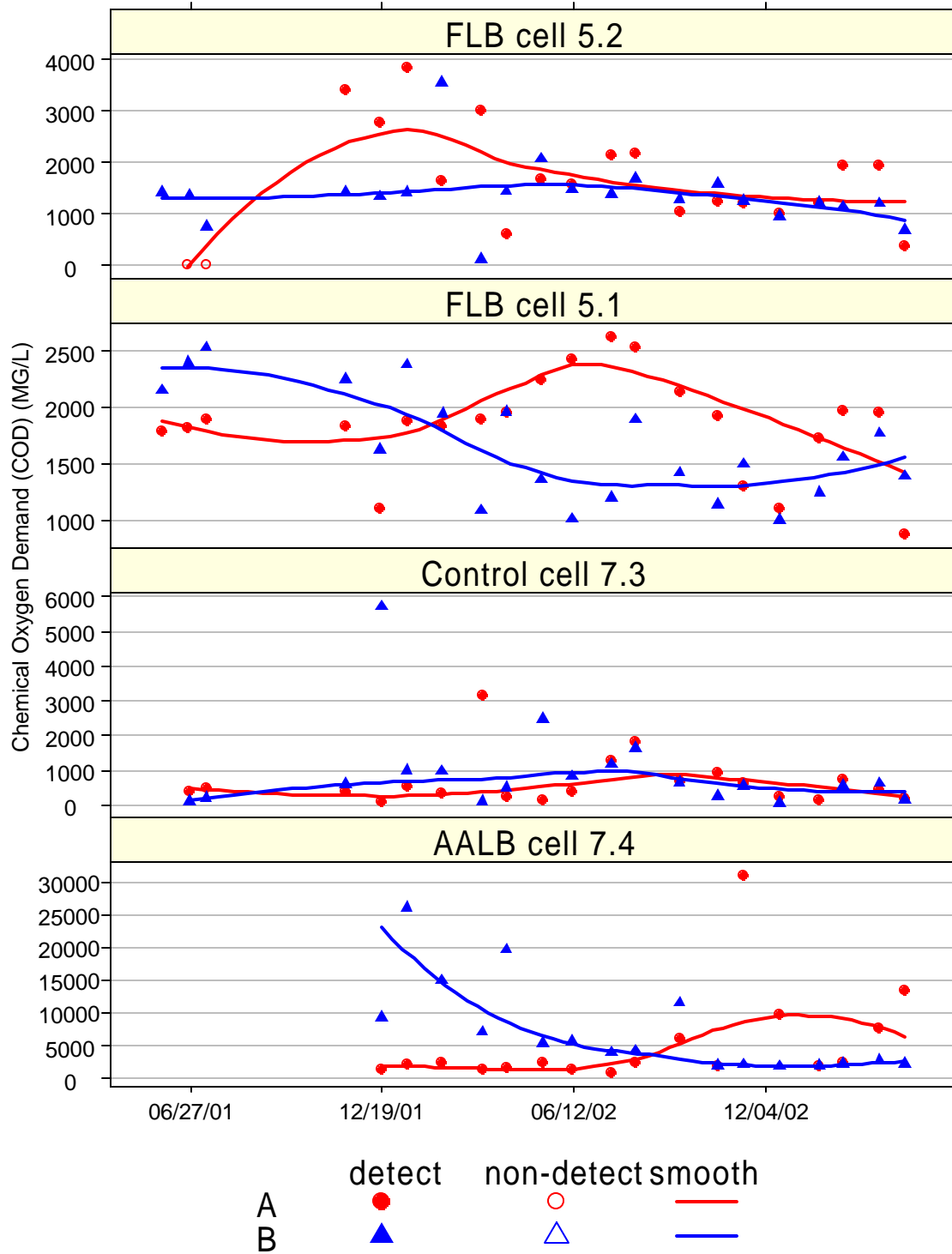


Chloride

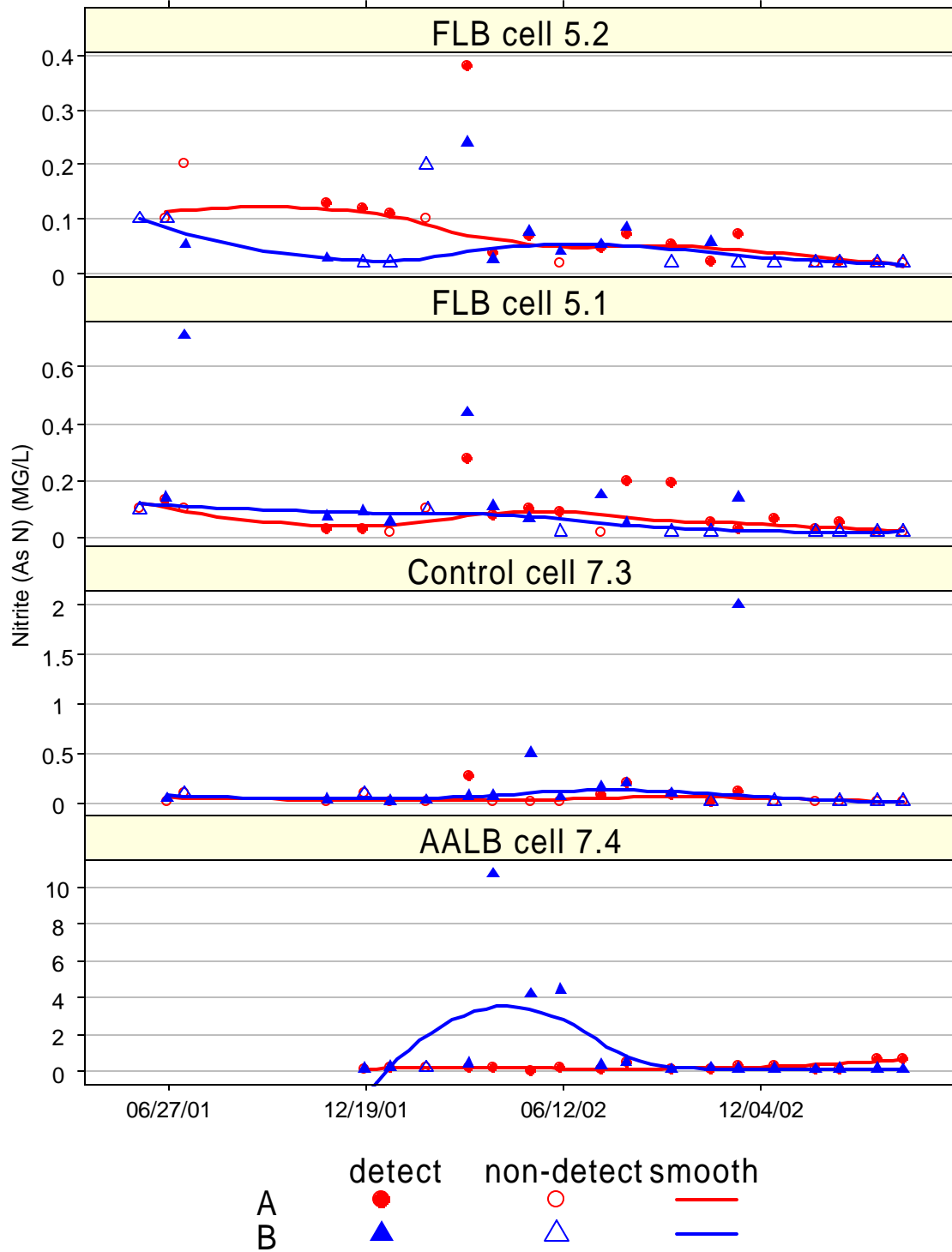


A detect non-detect smooth
 B ● ▲ ○ ▲ — —

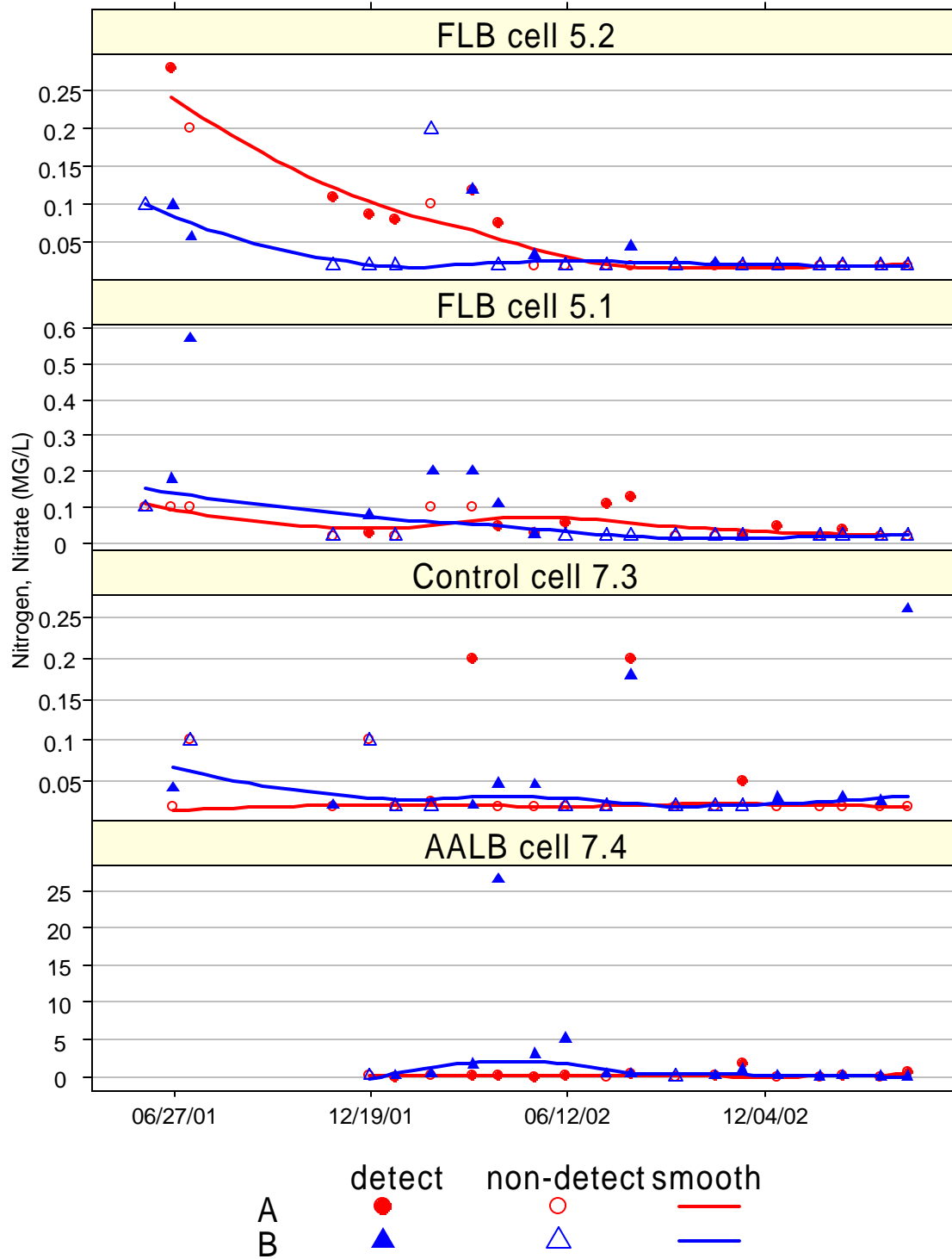
Chemical Oxygen Demand (COD)



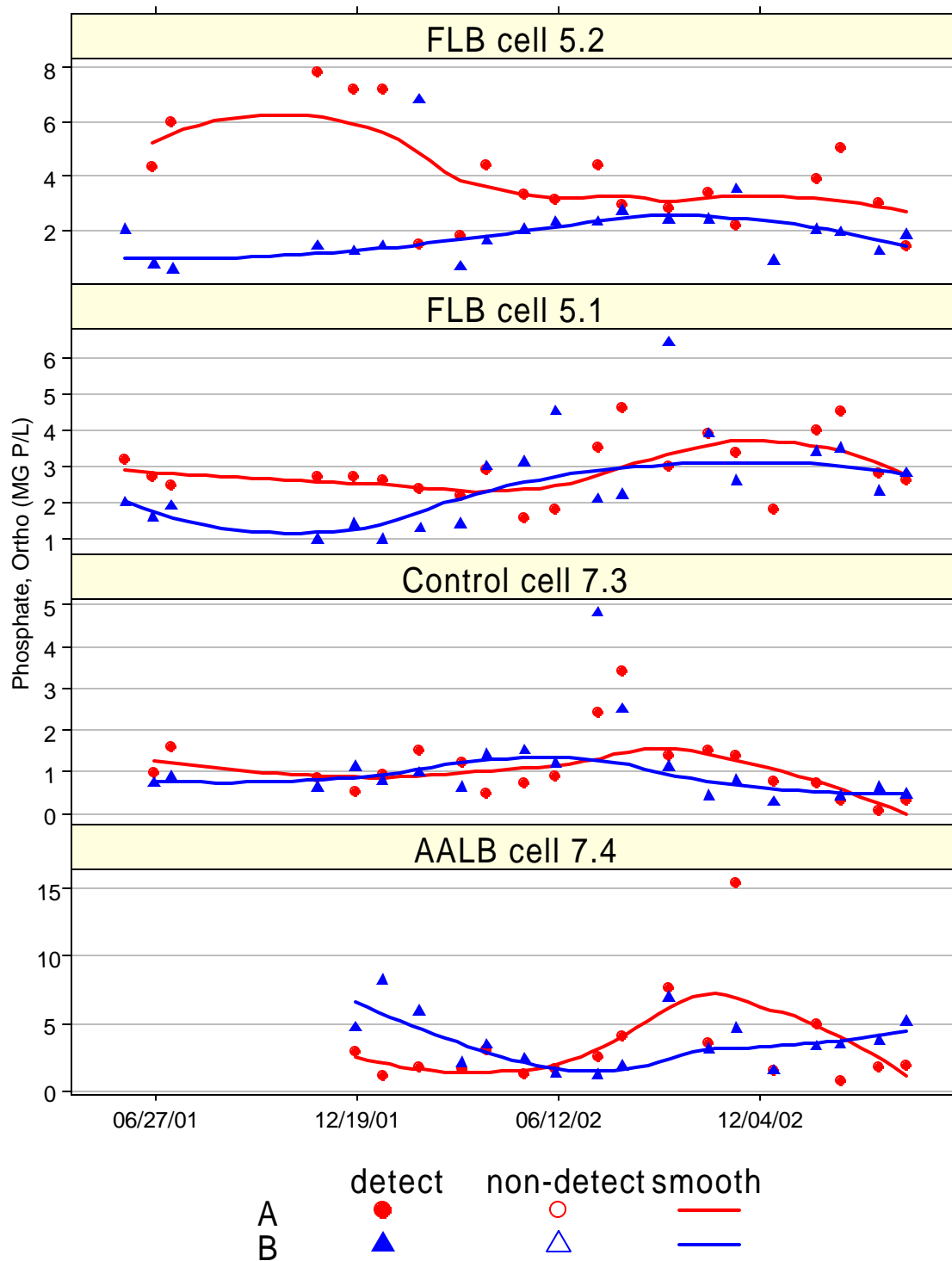
Nitrate (as N)



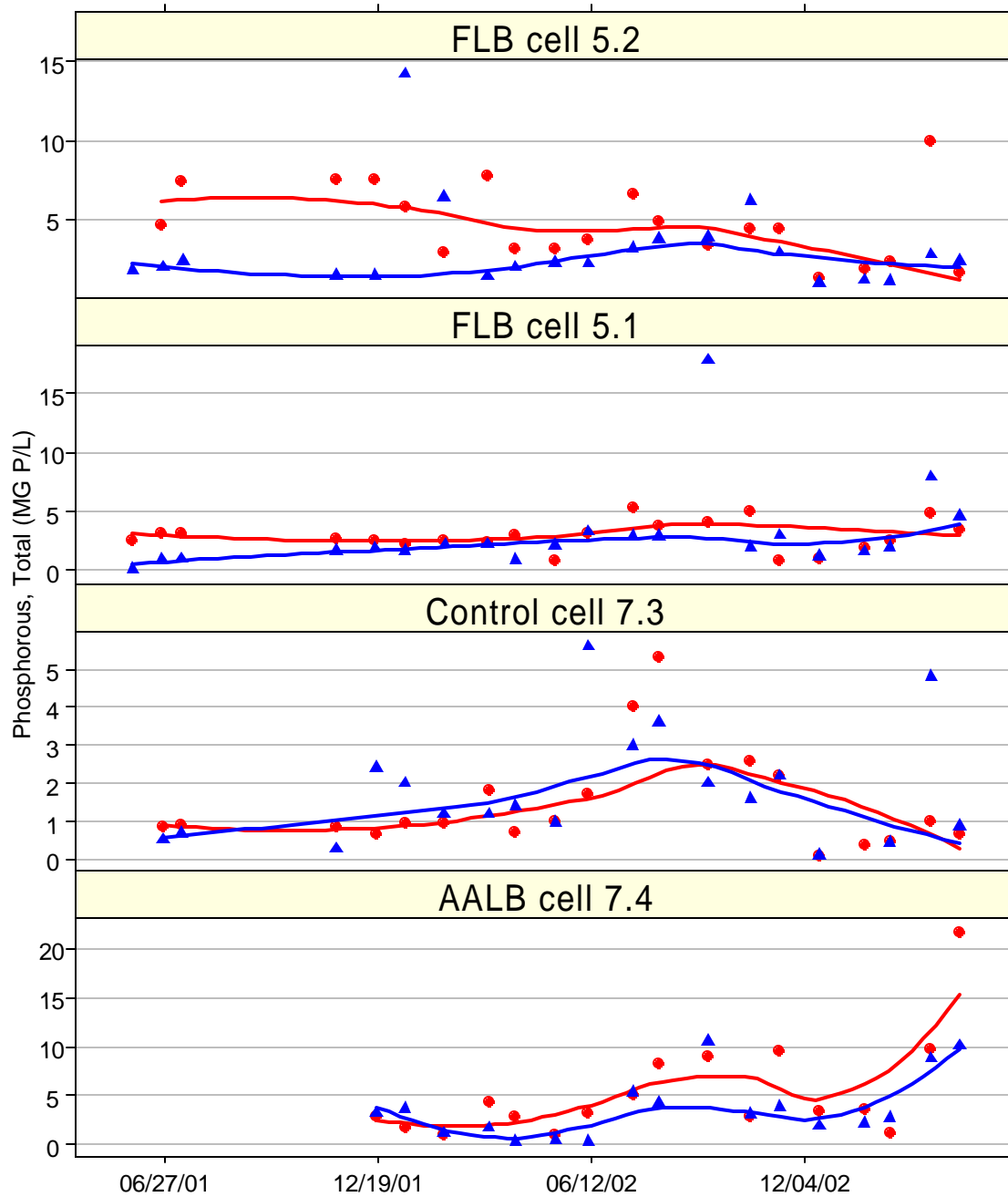
Nitrogen (Nitrate)



Phosphate, Ortho

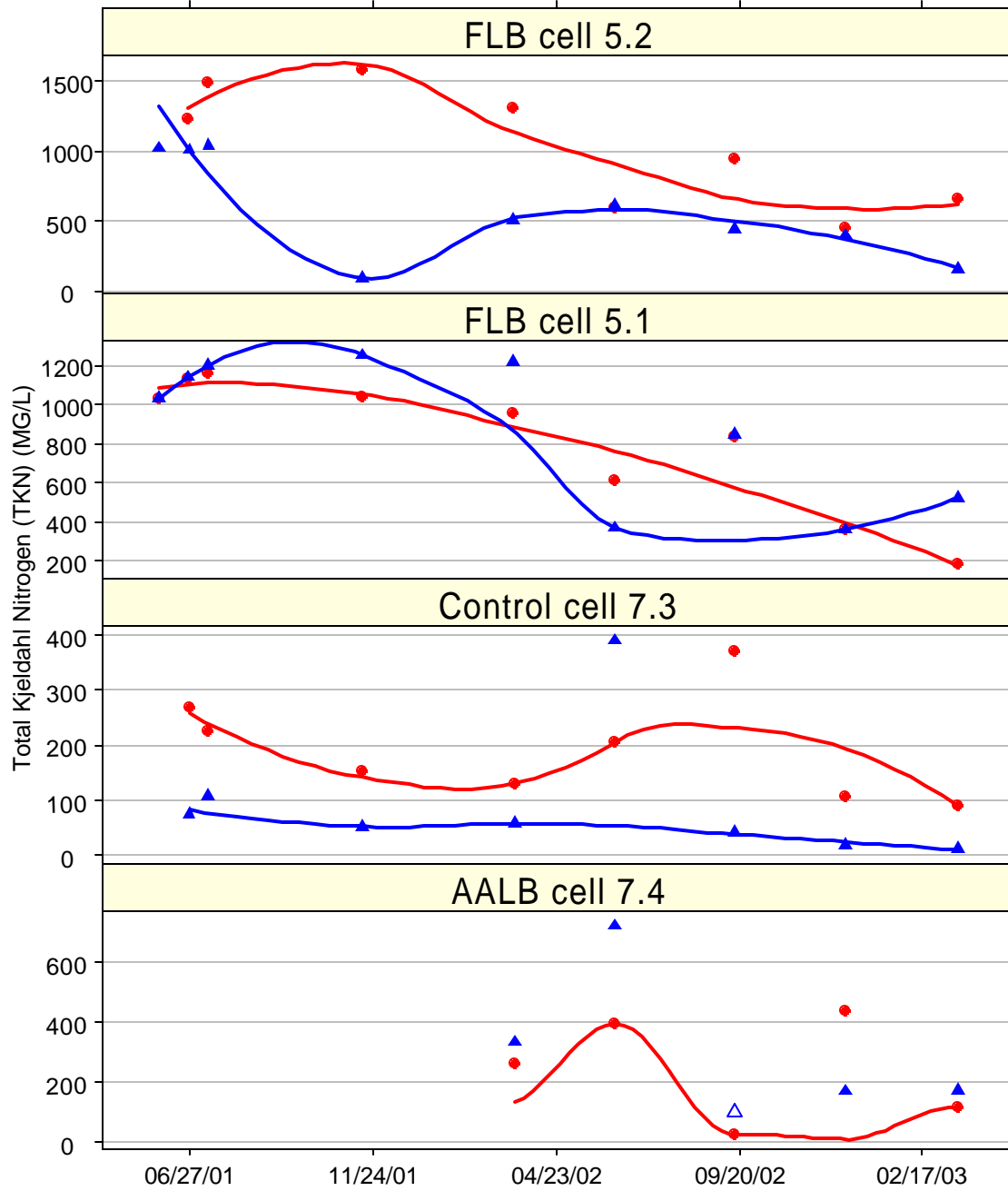


Phosphorous, Total



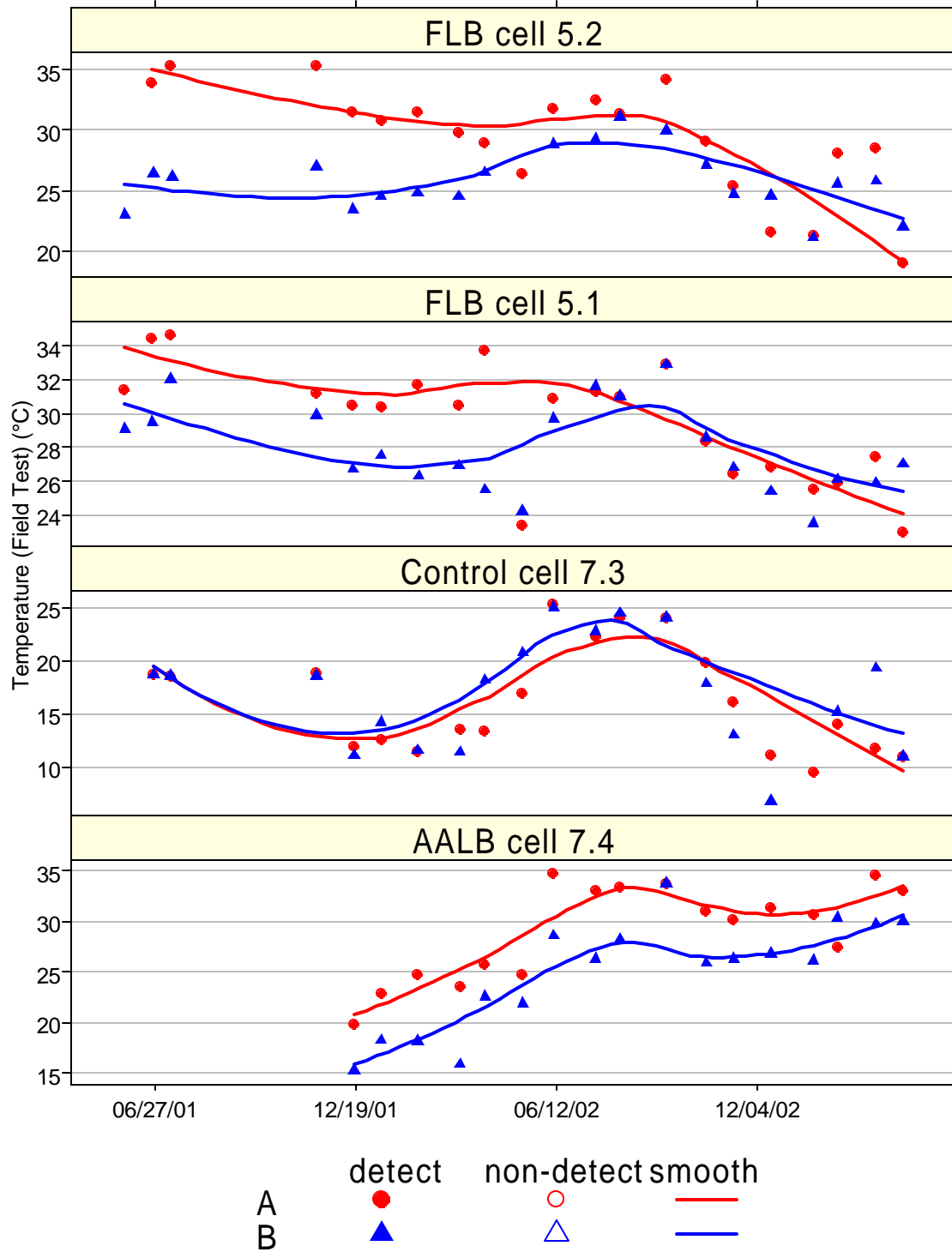
A detect non-detect smooth
 B ● ▲ ○ △ — —

Total Kjeldahl Nitrogen (TKN)

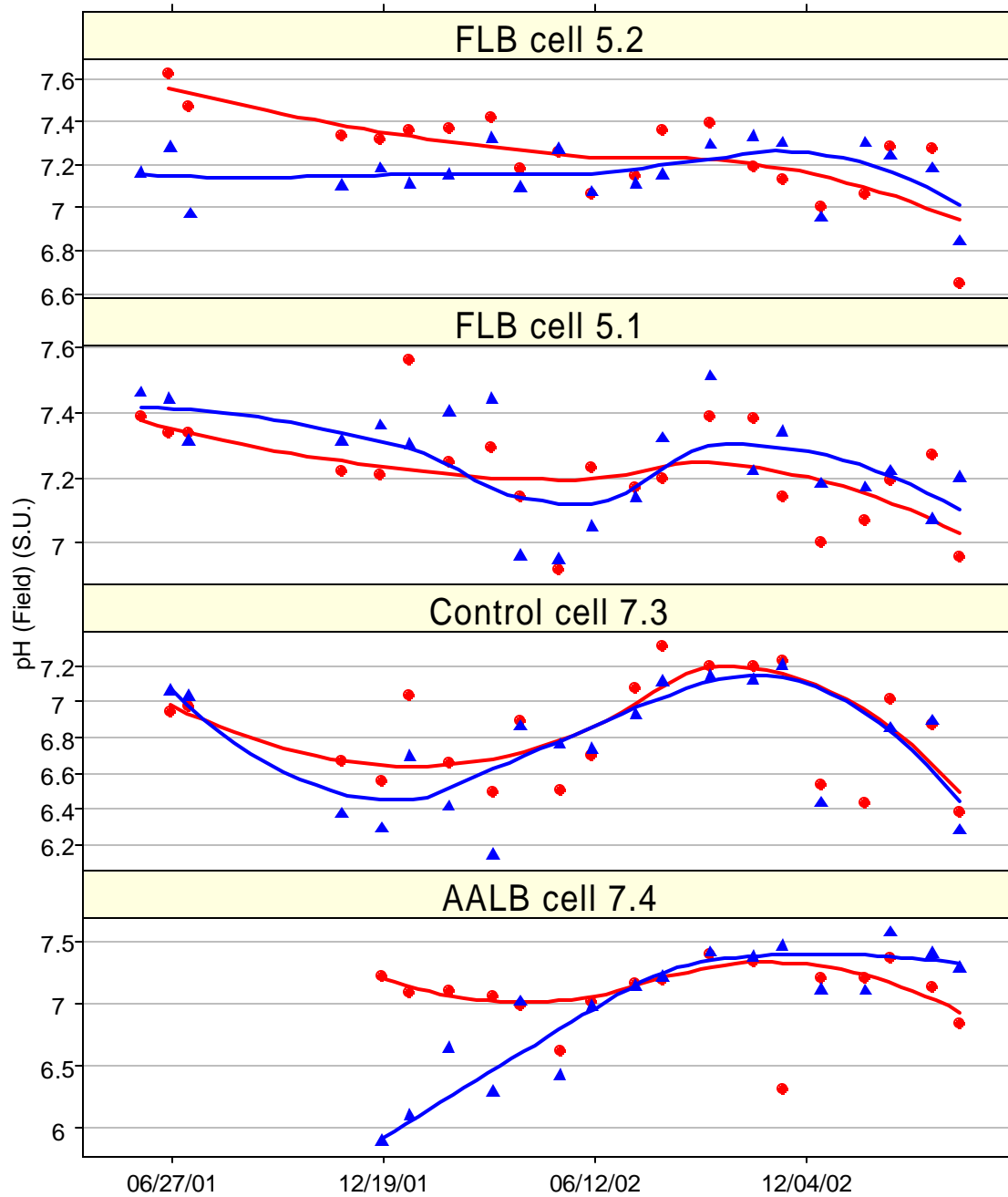


A detect non-detect smooth
 B ● ▲ ○ △ — —

Temperature



pH



A detect non-detect smooth
 B ● ▲ ○ △ — —

Summary

These time plots of the leachate data, in our opinion, give the most representative look into the leachate data. It can be seen that the replicate data (A/B) does not seem to be tightly grouped as would be hoped. It appears, in hindsight, that the (FLB cell 5.1A,FLB cell 5.2B) and (FLB cell 5.1B,FLB cell 5.2A) pairs may be more similar due to similar geometries. Even furthermore, (FLB cell 5.1B,FLB cell 5.2A) could be considered replicates and (FLB cell 5.1A,FLB cell 5.2B) could be considered two independent samples since they share no common boundary and are in somewhat different locations. There is evidence of these kinds of relationships in most of the leachate time plots. Due to this fact, we may try to re-group these samples, in terms of “replicate” status, in future analyses.

Locally weighted regression lines (LOESS) were included to assist the reader in viewing the data. The temporal correlation seems very adequate to justify including smoothed estimates of the data. Statistical tests will still be performed upon the actual data and these lines are only included to help the reader get a qualitative feel for the patterns in the plots.

There are two substantial BOD results, replicates in Control cell 7.3B and AALB cell 7.4B for 12/18/2001. These have been included in the exploratory data analysis and other analyses in lieu of any explanation or reason to disregard them. Although they are influential observations, their removal would probably not have much of an effect on model fitting efforts due to the overall variability of the data.

Influential Data Points to Validate

The following two tables list concentrations that are either extremely large when compared to all cells or large compared to the source cell. These values can have a large influence on statistical analyses and should be investigated further to determine whether they are data entry errors, outliers, or if events can be identified to explain their size.

Parameter	Result	Cell	AorB	Sampdate	Large Relative To
Biochemical Oxygen Demand	1.50E+04	AALB cell 7.4	A	11/14/2002	all cells
	5.44E+04	AALB cell 7.4	B	12/18/2001	all cells
	1.82E+03	Control cell 7.3	A	3/20/2002	rest of cell
	3.14E+04	Control cell 7.3	B	12/18/2001	all cells
	1.85E+03	Control cell 7.3	B	12/18/2001	rest of cell
	1.71E+03	Control cell 7.3	B	5/14/2002	rest of cell
	1.06E+03	FLB cell 5.1	A	5/13/2002	rest of cell
	4.80E+02	FLB cell 5.2	B	9/16/2002	rest of cell
	4.11E+02	FLB cell 5.2	B	10/21/2002	rest of cell
Chemical Oxygen Demand (COD)	3.09E+04	AALB cell 7.4	A	11/14/2002	all cells
	3.17E+03	Control cell 7.3	A	3/20/2002	rest of cell
	5.72E+03	Control cell 7.3	B	12/18/2001	rest of cell
	2.49E+03	Control cell 7.3	B	5/14/2002	rest of cell
Phosphorous, Total	2.16E+01	AALB cell 7.4	A	4/10/2003	all cells
	4.00E+00	Control cell 7.3	A	7/16/2002	rest of cell
	5.30E+00	Control cell 7.3	A	8/7/2002	rest of cell
	7.90E+00	FLB cell 5.1	B	3/18/2003	rest of cell
Total Kjeldahl Nitrogen (TKN)	7.21E+02	AALB cell 7.4	B	6/10/2002	rest of cell
	3.71E+02	Control cell 7.3	A	9/16/2002	rest of cell
	3.90E+02	Control cell 7.3	B	6/10/2002	rest of cell
Ammonia (As N)	2.72E+03	AALB cell 7.4	A	9/16/2002	rest of cell
	1.42E+03	Control cell 7.3	A	7/11/2001	rest of cell
	1.38E+03	Control cell 7.3	A	7/16/2002	rest of cell
	1.16E+03	Control cell 7.3	A	9/16/2002	rest of cell
	1.41E+03	Control cell 7.3	B	7/16/2002	rest of cell
	1.38E+03	Control cell 7.3	B	11/14/2002	rest of cell
	1.92E+04	FLB cell 5.1	A	6/25/2001	all cells
	1.09E+04	FLB cell 5.1	A	12/17/2001	all cells

The following parameter/cell combinations have many large values when compared to the rest of the cells.

Parameter	Cell	AorB
Biochemical Oxygen Demand	AALB cell 7.4	A
Biochemical Oxygen Demand	AALB cell 7.4	B
Chemical Oxygen Demand (COD)	AALB cell 7.4	A
Chemical Oxygen Demand (COD)	AALB cell 7.4	B

LEACHATE REPLICATE ANALYSIS

Analysis of Covariance

An analysis of covariance is performed to compare the A and B pairs of each cell for 5 critical parameters. The comparison of A and B pairs has been performed because the pairs are intended to be replicates within a treatment. However, the A and B pairs are subjected to differing factors like type and amount of waste disposed along with cell geometry. It was discovered that the pairs (FLB cell 5.1A, FLB cell 5.2B) and (FLB cell 5.1B, FLB cell 5.2A) have similar geometries so these pairs were also compared. In future analyses, comparisons may change based upon conclusions about which “replicate” grouping seems most appropriate (see comments in Summary for Leachate Time Plots).

The first step is to fit a polynomial (degree ≤ 3) regression model to all cells. Note that other non-linear models could have been utilized, but for simplicity only polynomial regression was attempted. Next, compare the model fits for A and B within a cell and chose a model that fits both well. Note that this choice may not be the model that fits each one best. However, a common model choice is necessary to perform an analysis of covariance. All model fits and the chosen models (in bold) are shown in the tables following the time and model plots. Many of the model fits are poor with insignificant parameters. The data are, in general, highly variable with small sample sizes. Also, there are many confounding factors that cannot be accounted for directly. These included geometry of cells, age of cells, type of waste in the cells and when the waste was placed in the cells.

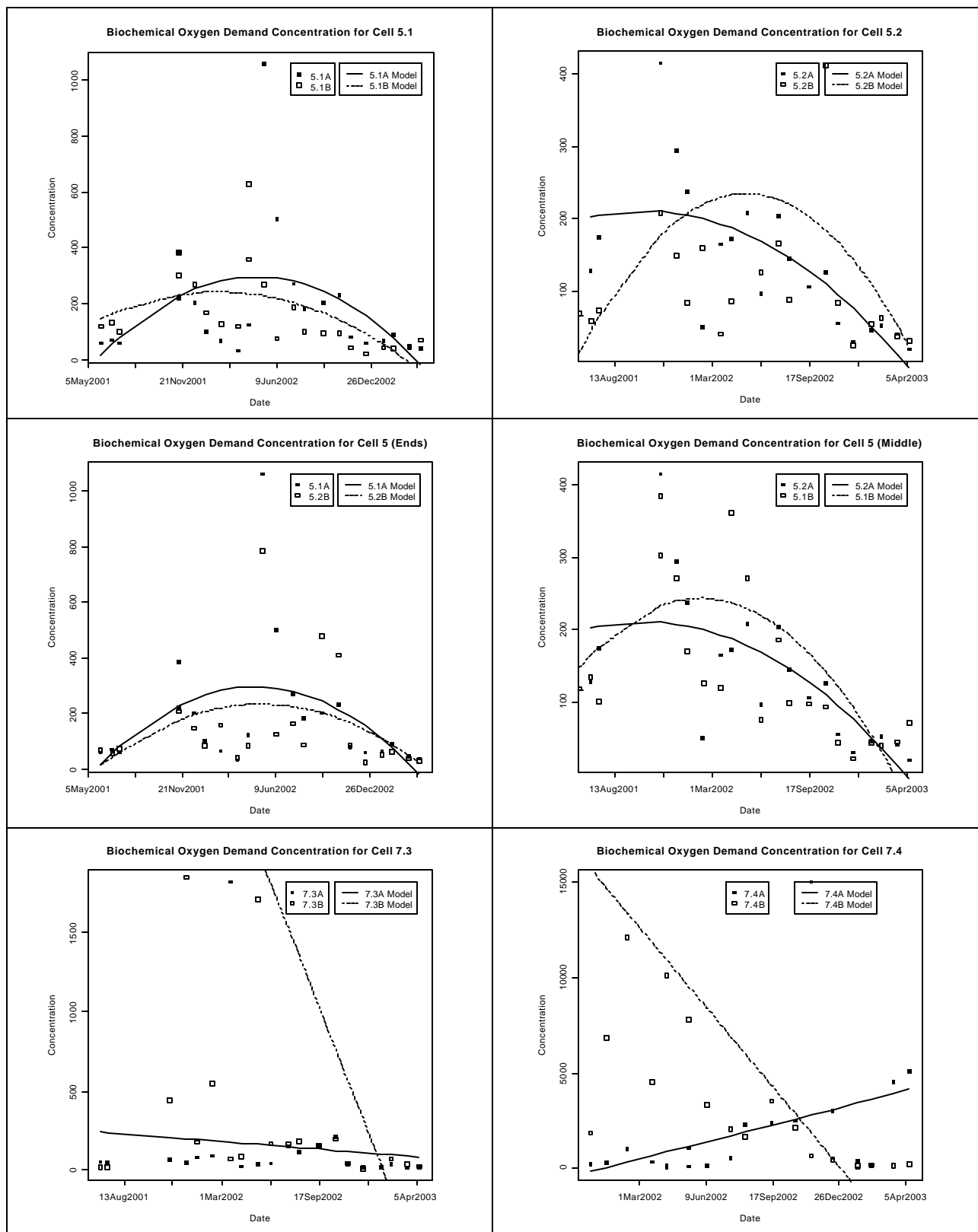
Statistical model comparison is shown in the table below. F-test p-values are provided in the right-side of the table. If all of the p-values are greater than 0.05, then the models are considered to coincide. Models with p-values between 0.05 and 0.10 have also been highlighted as marginally similar. Since many of the model fits are poor, models may be found to be statistically similar when the corresponding model plots look quite different.

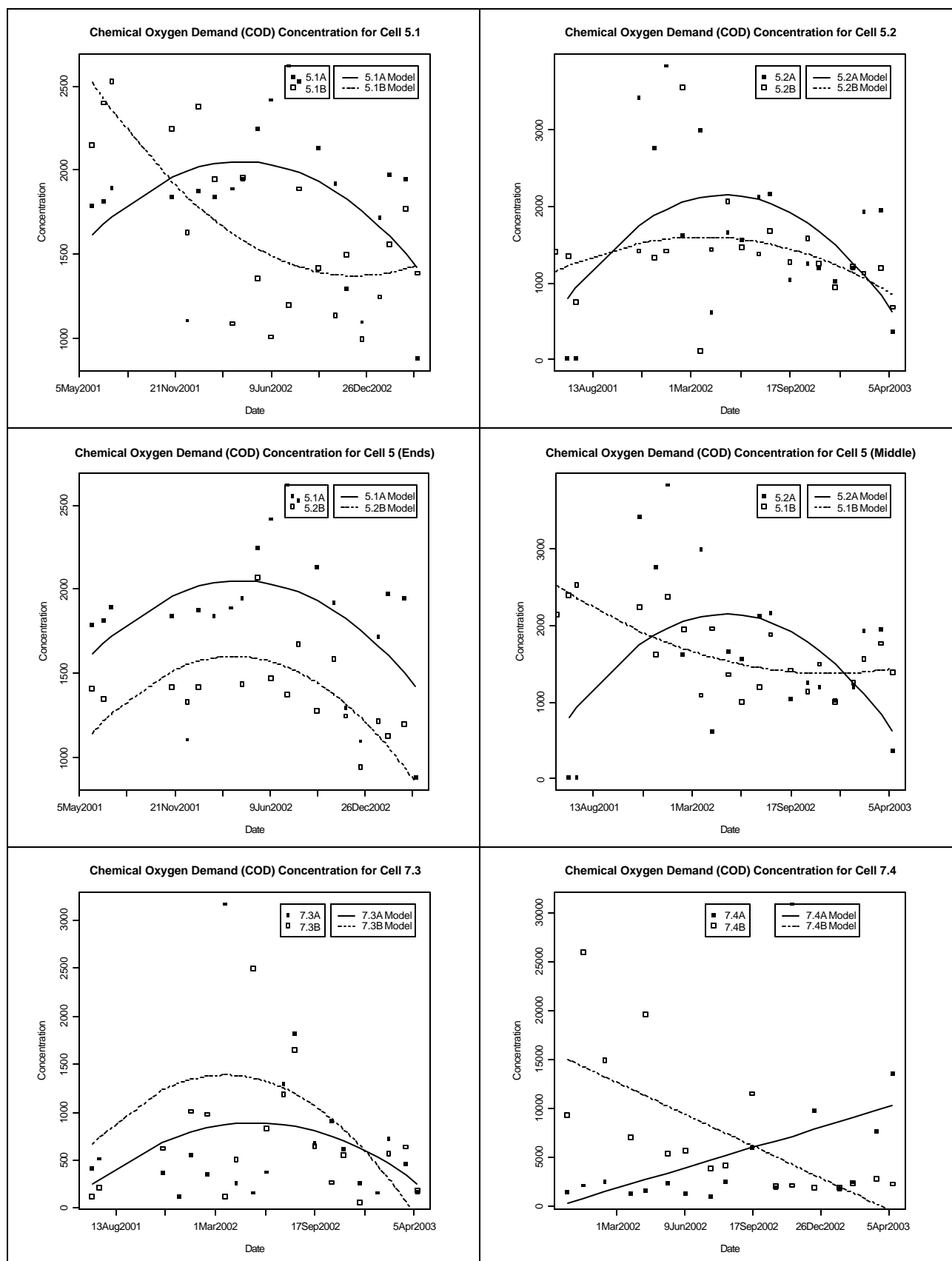
Following the analysis of covariance table are time and model plots. The plots provide a means of visually comparing the two models. Note that the chosen model that is plotted may contain insignificant parameters.

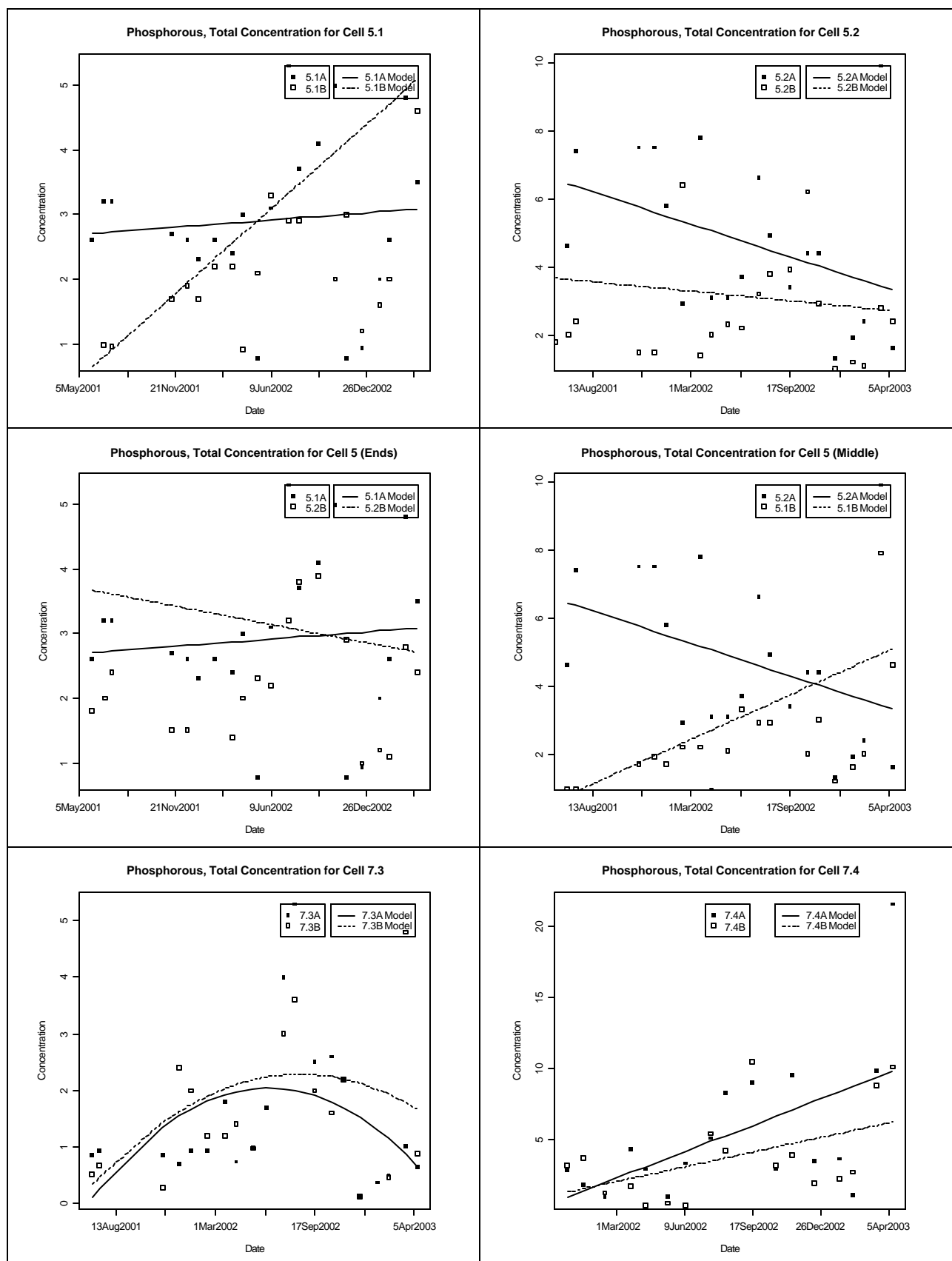
Analysis of Covariance Table

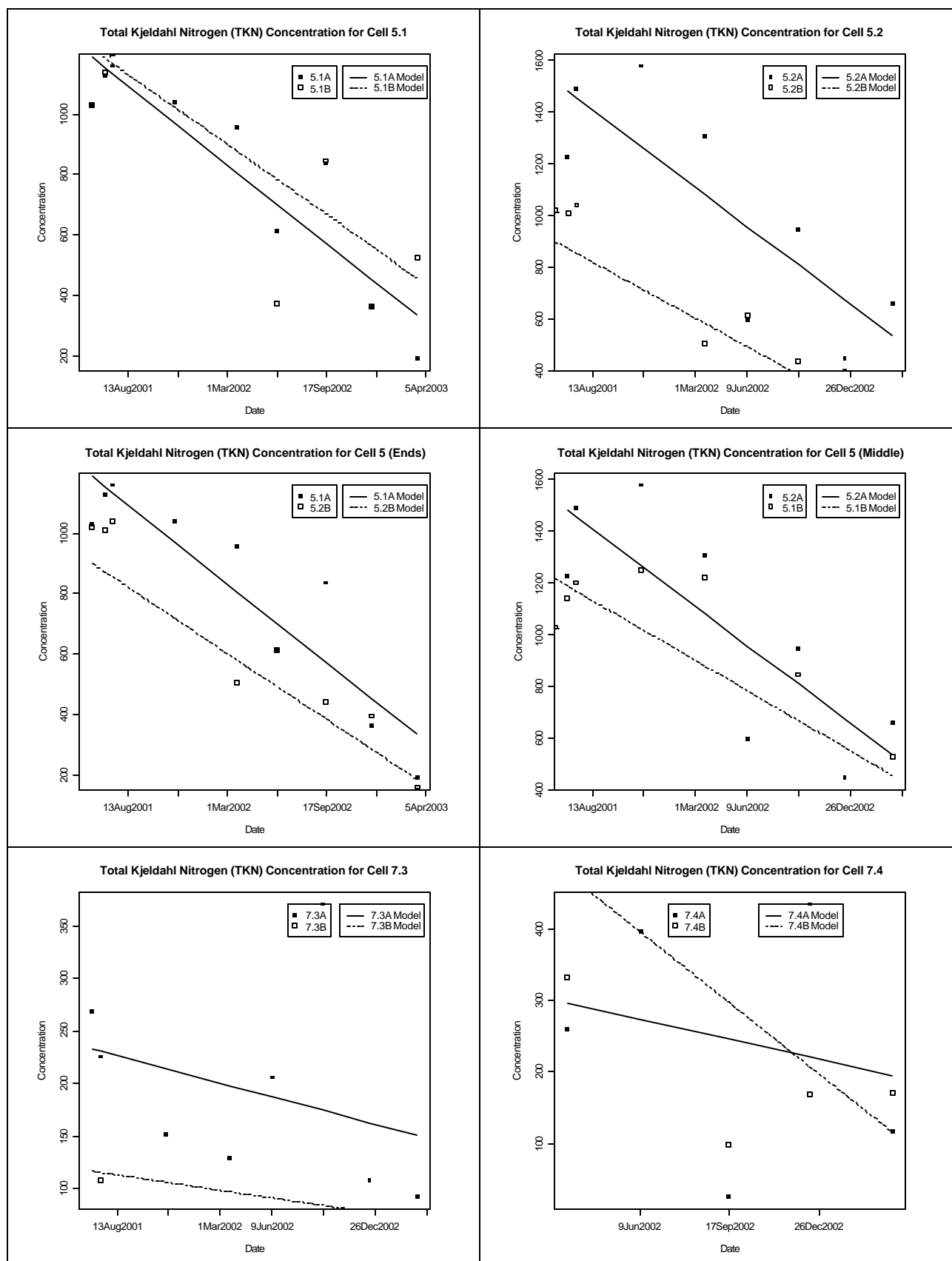
<u>Parameter</u>	Cells		Model	Statistically Similar?	Term			
					Cubic	Quadratic	Linear	Intercept
Biochemical Oxygen Demand	FLB cell 5.1A	FLB cell 5.1B	quadratic	yes		0.4285	0.4120	0.5936
	FLB cell 5.2A	FLB cell 5.2B	quadratic	yes		0.3123	0.1218	0.5612
	FLB cell 5.1A	FLB cell 5.2B	quadratic	yes		0.6442	0.8135	0.5925
	FLB cell 5.2a	FLB cell 5.1B	quadratic	yes		0.3412	0.7124	0.3570
	Control cell 7.3A	Control cell 7.3B	linear	yes			0.3466	0.3014
	AALB cell 7.4A	AALB cell 7.4B	linear	no			0.0051	0.1577
Chemical Oxygen Demand	FLB cell 5.1A	FLB cell 5.1B	quadratic	no		0.0071	0.0539	0.1670
	FLB cell 5.2A	FLB cell 5.2B	quadratic	yes		0.2199	0.8931	0.3836
	FLB cell 5.1A	FLB cell 5.2B	quadratic	no		0.8913	0.8475	0.0048
	FLB cell 5.2a	FLB cell 5.1B	quadratic	no		0.0057	0.4406	0.8481
	Control cell 7.3A	Control cell 7.3B	quadratic	yes		0.6555	0.4681	0.3949
	AALB cell 7.4A	AALB cell 7.4B	linear	no			0.0006	0.4461
Total Phosphorous	FLB cell 5.1A	FLB cell 5.1B	linear	yes			0.1490	0.8750
	<i>FLB cell 5.2A</i>	<i>FLB cell 5.2B</i>	linear	yes			0.4358	0.0710
	FLB cell 5.1A	FLB cell 5.2B	linear	yes			0.5734	0.7361

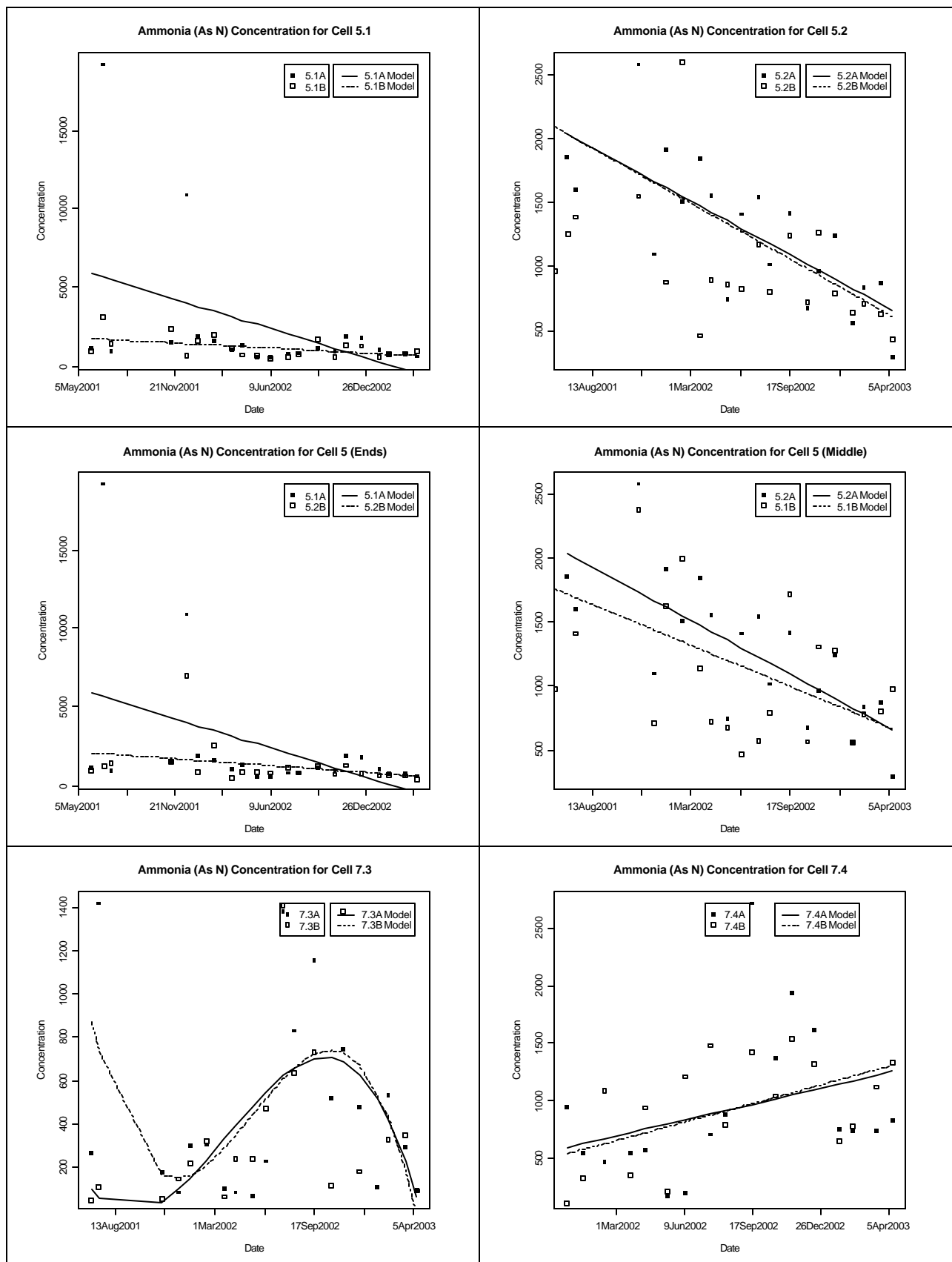
	FLB cell 5.2a	FLB cell 5.1B	linear	no			0.0235	0.1021
	Control cell 7.3A	Control cell 7.3B	quadratic	yes		0.7175	0.5782	0.4107
	AALB cell 7.4A	AALB cell 7.4B	linear	yes			0.3446	0.2134
Total Kjeldahl Nitrogen	FLB cell 5.1A	FLB cell 5.1B	linear	yes			0.7447	0.4744
	FLB cell 5.2A	FLB cell 5.2B	linear	no			0.4873	0.0028
	FLB cell 5.1A	FLB cell 5.2B	linear	no			0.6420	0.0374
	FLB cell 5.2a	FLB cell 5.1B	linear	yes			0.5512	0.2042
	<i>Control cell 7.3A</i>	<i>Control cell 7.3B</i>	linear	yes			0.8292	0.0965
	AALB cell 7.4A	AALB cell 7.4B	linear	yes			0.5332	0.7070
Ammonia (As N)	<i>FLB cell 5.1A</i>	<i>FLB cell 5.1B</i>	linear	yes			0.0841	0.1729
	FLB cell 5.2A	FLB cell 5.2B	linear	yes			0.9638	0.9366
	FLB cell 5.1A	FLB cell 5.2B	linear	yes			0.1232	0.2320
	FLB cell 5.2a	FLB cell 5.1B	linear	yes			0.5407	0.5333
	Control cell 7.3A	Control cell 7.3B	cubic	yes	0.4256	0.2347	0.2270	0.5138
	AALB cell 7.4A	AALB cell 7.4B	linear	yes			0.8530	0.9939











Biochemical Oxygen Demand

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.152412e+02	0.04552217	2.682627e+02	0.0001481634
	date	-7.337726e-02	0.76794800	-2.890203e-01	0.0553831481
quadratic	intercept	1.827701e+01	0.88736979	1.473795e+02	0.0584492734
	date	1.696082e+00	0.05274789	7.663082e-01	0.1151858269
	date^2	-2.576048e-03	0.03722919	-1.532262e-03	0.0284958364
cubic	intercept	3.154714e+01	0.83555604	7.426527e+01	0.3593276353
	date	1.379486e+00	0.48586123	2.510360e+00	0.0232186664
	date^2	-1.338671e-03	0.84888488	-8.369213e-03	0.0334183914
	date^3	-1.231015e-06	0.85813385	6.814990e-06	0.0727081641

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.588700e+02	1.675535e-06	1.559619e+02	0.08466699
	date	-3.346164e-01	1.732076e-03	2.602369e-05	0.99989973
quadratic	intercept	2.024532e+02	8.140932e-04	1.455682e+01	0.89427285
	date	1.587610e-01	6.232715e-01	1.285332e+00	0.07736977
	date^2	-7.296590e-04	1.242635e-01	-1.876052e-03	0.06691669
cubic	intercept	1.642517e+02	6.746645e-03	6.282264e+01	0.61710203
	date	1.146506e+00	1.061819e-01	3.714552e-02	0.98229640
	date^2	-4.744217e-03	7.238006e-02	3.008179e-03	0.61900326
	date^3	4.138439e-06	1.177996e-01	-4.841674e-06	0.41606637

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.436908e+02	0.2221977	4.552255e+03	0.1593952
	date	-2.445069e-01	0.6113035	-7.852682e+00	0.3235841
quadratic	intercept	3.965700e+01	0.8840587	3.376253e+03	0.4712576
	date	1.546337e+00	0.3780156	2.273288e+00	0.9395064
	date^2	-2.654637e-03	0.2907304	-1.487198e-02	0.7260773
cubic	intercept	-1.974563e+01	0.9491376	4.574563e+02	0.9293698
	date	3.095429e+00	0.4358343	7.216667e+01	0.2679709
	date^2	-8.968965e-03	0.5394232	-2.989309e-01	0.2127126
	date^3	6.522872e-06	0.6598928	2.936991e-04	0.2281026

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	-1.494479e+02	0.9146097	1.567017e+04	0.003388943
	date	8.937710e+00	0.0867887	-4.169637e+01	0.023164682
quadratic	intercept	-6.318798e+02	0.7647328	2.076381e+04	0.002358366
	date	1.520903e+01	0.4677170	-1.227301e+02	0.055485451
	date^2	-1.291843e-02	0.7557589	1.756980e-01	0.174735767
cubic	intercept	3.850463e+02	0.8816165	2.311238e+04	0.003205906
	date	-1.322407e+01	0.7722729	-2.170226e+02	0.132124827
	date^2	1.423817e-01	0.5294259	7.182375e-01	0.330033545
	date^3	-2.197728e-04	0.4856335	-7.767112e-04	0.451624289

Chemical Oxygen Demand (COD)

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.960465e+03	1.081922e-08	2.235893e+03	3.552959e-11
	date	-3.061233e-01	5.386668e-01	-1.573900e+00	8.013883e-04
quadratic	intercept	1.615873e+03	6.124507e-06	2.520544e+03	3.802319e-10
	date	2.834956e+00	9.905660e-02	-4.168465e+00	5.202189e-03
	date^2	-4.588793e-03	6.006205e-02	3.790489e-03	5.415787e-02
cubic	intercept	1.825067e+03	4.699406e-06	2.365736e+03	7.849645e-09
	date	-2.632638e+00	4.884627e-01	-1.195621e-01	9.689652e-01
	date^2	1.684489e-02	2.259622e-01	-1.208195e-02	2.840335e-01
	date^3	-2.126205e-05	1.235399e-01	1.574490e-05	1.590089e-01

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.840461e+03	0.002178118	1.536272e+03	4.519746e-05
	date	-5.616490e-01	0.661432084	-4.643965e-01	5.132532e-01
quadratic	intercept	8.047374e+02	0.232099393	1.147920e+03	7.569550e-03
	date	8.495986e+00	0.055486304	3.065543e+00	2.223960e-01
	date^2	-1.339539e-02	0.035815796	-5.152352e-03	1.471131e-01
cubic	intercept	5.576066e+01	0.928185709	1.139109e+03	2.025952e-02
	date	2.786167e+01	0.002354332	3.293389e+00	5.870335e-01
	date^2	-9.210465e-02	0.005135538	-6.043928e-03	7.811988e-01
	date^3	8.113807e-05	0.012548053	8.838069e-07	9.668344e-01

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	7.102012e+02	0.05999102	1.428613e+03	0.03666348
	date	-1.193484e-01	0.89215459	-1.331828e+00	0.41302080
quadratic	intercept	2.456102e+02	0.61726719	6.683128e+02	0.44712134
	date	3.958456e+00	0.21549391	5.385694e+00	0.33984764
	date^2	-6.044686e-03	0.18588644	-1.005476e-02	0.21877505
cubic	intercept	3.643681e+02	0.51560667	1.432952e+02	0.88009151
	date	8.615070e-01	0.90310030	1.911237e+01	0.12987300
	date^2	6.578941e-03	0.80137794	-6.599695e-02	0.15513754
	date^3	-1.304055e-05	0.62496324	5.766683e-05	0.21701552

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.728821e+02	0.93308625	1.500991e+04	1.144936e-05
	date	2.090255e+01	0.08442847	-3.249839e+01	1.337172e-03
quadratic	intercept	2.807360e+02	0.95199798	1.775043e+04	6.699188e-05
	date	2.079518e+01	0.65019472	-6.996677e+01	4.120704e-02
	date^2	2.239602e-04	0.99805724	7.814792e-02	2.328388e-01
cubic	intercept	2.533684e+03	0.65754826	1.702006e+04	8.242883e-04
	date	-4.896104e+01	0.65094440	-4.735300e+01	5.360385e-01
	date^2	3.802693e-01	0.48384465	-4.505629e-02	9.053947e-01
	date^3	-5.314646e-04	0.47747192	1.722917e-04	7.418435e-01

Phosphorous, Total

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.707463e+00	0.0001475468	6.418077e-01	0.6942815
	date	5.626158e-04	0.6850799049	6.557450e-03	0.1034484
quadratic	intercept	2.883161e+00	0.0018398618	1.223737e-01	0.9565856
	date	-1.038930e-03	0.8384629711	1.129205e-02	0.4332161
	date^2	2.339693e-06	0.7437386096	-6.916933e-06	0.7304152
cubic	intercept	2.928984e+00	0.0053724566	6.105435e-01	0.8146521
	date	-2.236583e-03	0.8579301840	-1.475719e-03	0.9662528
	date^2	7.034650e-06	0.8759199590	4.313505e-05	0.7321341
	date^3	-4.657362e-09	0.9158594354	-4.964979e-08	0.6874593

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	6.426692e+00	1.403425e-05	3.672043e+00	0.01329640
	date	-4.754063e-03	9.184472e-02	-1.416524e-03	0.66363669
quadratic	intercept	6.755890e+00	4.716200e-04	2.188115e+00	0.23744612
	date	-7.632967e-03	4.543398e-01	1.207169e-02	0.30265865
	date^2	4.257629e-06	7.675323e-01	-1.968761e-05	0.23295379
cubic	intercept	6.001566e+00	3.341393e-03	1.493954e+00	0.47723110
	date	1.187098e-02	5.984809e-01	3.002315e-02	0.28994542
	date^2	-7.501358e-05	3.703287e-01	-8.993276e-05	0.37618268
	date^3	8.171736e-08	3.372653e-01	6.963309e-08	0.48161812

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.290169e+00	0.05730722	1.178021e+00	0.1229711
	date	5.324213e-04	0.73655511	1.886232e-03	0.3167403
quadratic	intercept	1.013494e-01	0.90247044	3.305437e-01	0.7430964
	date	1.096692e-02	0.04991549	9.373992e-03	0.1579260
	date^2	-1.546745e-05	0.05206245	-1.120765e-05	0.2348907
cubic	intercept	8.479099e-01	0.32103152	3.526714e-01	0.7608092
	date	-8.501764e-03	0.43097181	8.795457e-03	0.5539467
	date^2	6.388979e-05	0.11964919	-8.849872e-06	0.8713087
	date^3	-8.197817e-08	0.05458430	-2.430469e-09	0.9650235

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	9.293295e-01	0.65199414	1.273296e+00	0.35193662
	date	1.855459e-02	0.02026386	1.034462e-02	0.04345766
quadratic	intercept	2.915159e+00	0.31396703	2.565731e+00	0.18332603
	date	-8.595683e-03	0.75786922	-7.325562e-03	0.68945135
	date^2	5.662741e-05	0.32110025	3.685475e-05	0.32528984
cubic	intercept	1.563474e-01	0.96156958	2.235548e+00	0.34352471
	date	7.682319e-02	0.22462179	2.897617e-03	0.94735924
	date^2	-4.087511e-04	0.19715947	-1.884311e-05	0.93144676
	date^3	6.507966e-07	0.14004323	7.788924e-08	0.79646740

Total Kjeldahl Nitrogen (TKN)

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.186743e+03	1.545508e-06	1.216155e+03	4.280723e-05
	date	-1.301889e+00	5.516811e-04	-1.160246e+00	1.584045e-02
quadratic	intercept	1.101968e+03	8.686775e-06	1.170280e+03	4.503441e-04
	date	-1.408898e-02	9.838737e-01	-4.633607e-01	7.560703e-01
	date^2	-2.098476e-03	9.224937e-02	-1.135579e-03	6.293948e-01
cubic	intercept	1.104722e+03	9.831374e-05	1.052960e+03	1.960242e-03
	date	-1.180686e-01	9.527674e-01	3.964969e+00	2.992721e-01
	date^2	-1.667458e-03	8.293180e-01	-1.949198e-02	2.014800e-01
	date^3	-4.381939e-07	9.549029e-01	1.866199e-05	2.199153e-01

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.482229e+03	8.902959e-05	8.991622e+02	0.0003929878
	date	-1.504524e+00	1.289419e-02	-1.091677e+00	0.0252868669
quadratic	intercept	1.451165e+03	8.733119e-04	9.819408e+02	0.0012002987
	date	-1.054577e+00	5.503233e-01	-2.340766e+00	0.1544070832
	date^2	-7.506798e-04	7.872231e-01	2.033163e-03	0.4011545800
cubic	intercept	1.334024e+03	2.082921e-03	1.148830e+03	0.0004901504
	date	4.289159e+00	2.813821e-01	-8.540944e+00	0.0266411505
	date^2	-2.419000e-02	1.588921e-01	2.769309e-02	0.0478667655
	date^3	2.491795e-05	1.648856e-01	-2.607333e-05	0.0582659710

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.329992e+02	0.006583895	1.163771e+02	0.1885619
	date	-1.302736e-01	0.431311936	-7.249440e-02	0.7436343
quadratic	intercept	2.193082e+02	0.029986841	6.413407e+01	0.5132520
	date	6.935795e-02	0.910668726	6.892750e-01	0.3908422
	date^2	-3.339230e-04	0.737619354	-1.274209e-03	0.3284838
cubic	intercept	2.629507e+02	0.014521089	7.794385e+01	0.5094423
	date	-1.954824e+00	0.171120388	4.876317e-02	0.9815769
	date^2	8.569131e-03	0.147270229	1.542984e-03	0.8578281
	date^3	-9.482668e-06	0.132005299	-3.000600e-06	0.7416922

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.968319e+02	0.1422521	4.751919e+02	0.07980778
	date	-2.797538e-01	0.7078643	-9.854460e-01	0.31771615
quadratic	intercept	2.820791e+02	0.3322031	4.746016e+02	0.22190046
	date	5.367207e-02	0.9872122	-9.721032e-01	0.81326064
	date^2	-9.208126e-04	0.9175455	-3.684848e-05	0.99728299
cubic	intercept	3.072219e+02	0.5206202	3.737667e+02	0.42000641
	date	-1.790548e+00	0.8795787	6.424126e+00	0.57964067
	date^2	1.309786e-02	0.8730695	-5.625863e-02	0.50601183
	date^3	-2.561497e-05	0.8625165	1.027286e-04	0.50167999

Ammonia (As N)

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	5.891555e+03	0.004380627	1.757537e+03	3.485958e-06
	date	-9.398683e+00	0.043475747	-1.605124e+00	2.306600e-02
quadratic	intercept	7.657295e+03	0.005736417	1.985035e+03	4.008765e-05
	date	-2.549405e+01	0.117999149	-3.678752e+00	1.332392e-01
	date^2	2.351368e-02	0.294740536	3.029433e-03	3.682352e-01
cubic	intercept	7.502048e+03	0.017110290	1.870821e+03	3.792349e-04
	date	-2.143644e+01	0.580445833	-6.915495e-01	9.045288e-01
	date^2	7.607298e-03	0.956424707	-8.680947e-03	6.770770e-01
	date^3	1.577901e-05	0.907820805	1.161628e-05	5.699373e-01

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.037352e+03	1.323264e-09	2.088572e+03	0.002769706
	date	-2.102609e+00	1.555545e-04	-2.175365e+00	0.149737373
quadratic	intercept	1.861285e+03	1.087967e-06	1.646251e+03	0.062300131
	date	-5.628595e-01	7.303572e-01	1.845129e+00	0.729955954
	date^2	-2.277145e-03	3.327963e-01	-5.868373e-03	0.436791548
cubic	intercept	1.805746e+03	1.100234e-05	1.036460e+03	0.271721227
	date	8.731488e-01	8.137686e-01	1.761472e+01	0.166983484
	date^2	-8.113609e-03	5.541618e-01	-6.757577e-02	0.142364982
	date^3	6.016566e-06	6.648267e-01	6.116972e-05	0.172571765

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	4.919822e+02	0.032316700	1.471974e+02	0.45166176
	date	-8.922344e-02	0.865743229	6.559115e-01	0.19081172
quadratic	intercept	5.113659e+02	0.111779808	-1.258665e+02	0.62786942
	date	-2.593578e-01	0.895440894	3.068528e+00	0.07740272
	date^2	2.521967e-04	0.928534768	-3.611196e-03	0.14120338
cubic	intercept	8.705869e+02	0.006949358	9.829742e+01	0.71117510
	date	-9.627064e+00	0.015995287	-2.792277e+00	0.41441411
	date^2	3.843636e-02	0.010191162	2.027414e-02	0.11997870
	date^3	-3.944528e-05	0.009657178	-2.462170e-05	0.06724930

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	5.906813e+02	0.06133527	5.345041e+02	0.01109482
	date	1.383019e+00	0.20084230	1.611618e+00	0.02616511
quadratic	intercept	2.714398e+02	0.50847802	2.400521e+02	0.33197643
	date	5.747689e+00	0.16455342	5.637367e+00	0.03033601
	date^2	-9.103408e-03	0.26791563	-8.396519e-03	0.09642544
cubic	intercept	8.731121e+02	0.04565582	1.866690e+02	0.53913615
	date	-1.288140e+01	0.10869700	7.290225e+00	0.21575358
	date^2	9.239150e-02	0.02785519	-1.740161e-02	0.54445124
	date^3	-1.419329e-04	0.01618144	1.259294e-05	0.74881839

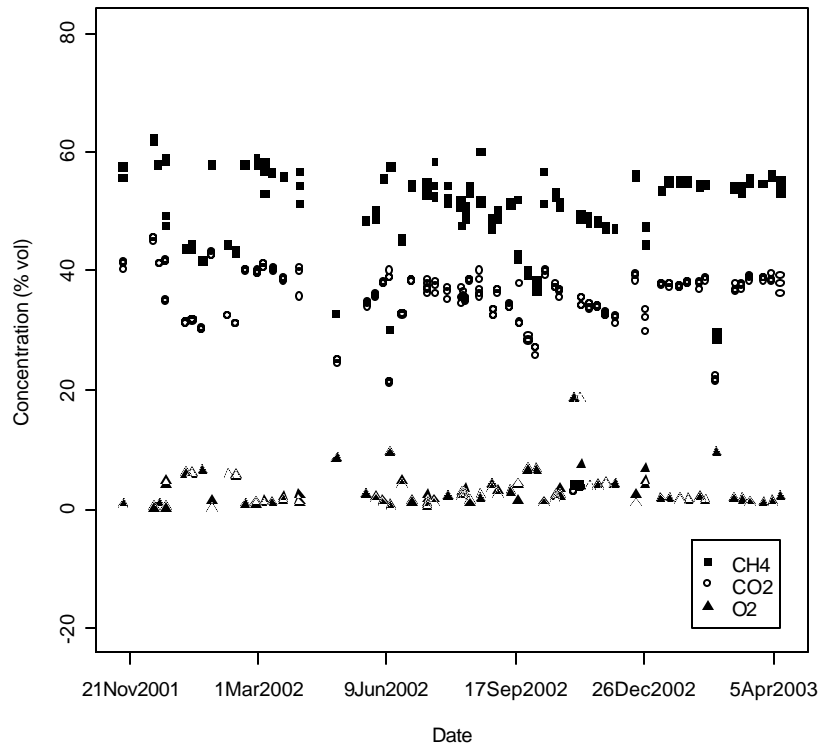
FIELD GAS TIME PLOTS

Summary

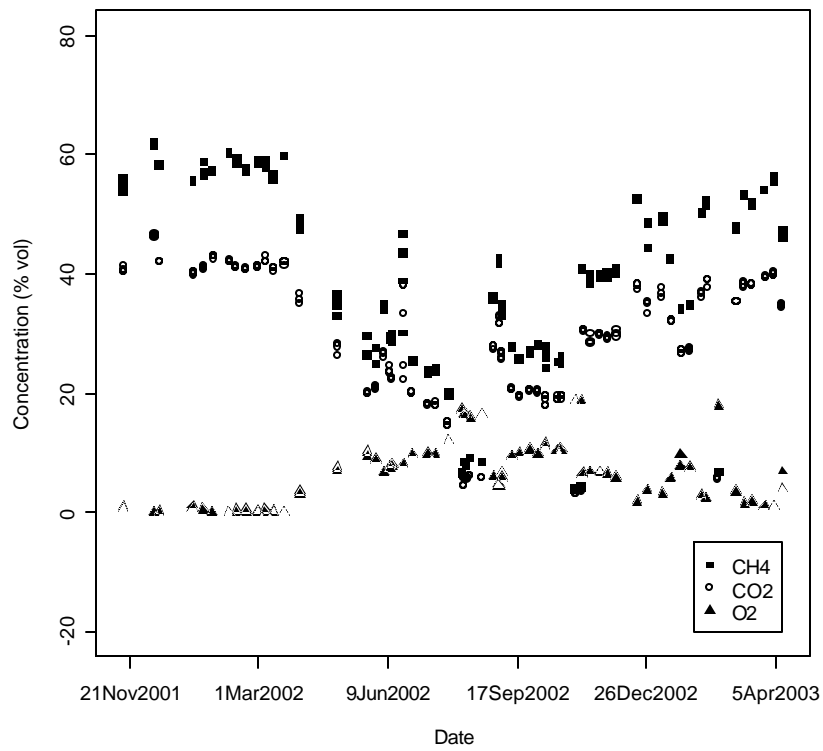
The field gas plots for the control cells and FLB cell 5.1 are very similar in nature. Compositions are the same with all exhibiting a flat linear behavior in time. FLB cell 5.1 shows a slightly higher degree of variability than the control cells.

FLB cell 5.2 is quite different than the other cells. At the beginning of observation, gas composition is quite similar to the other cells. Then on approximately March 1, 2002 after a period of flat linear behavior, there is a dip in methane and carbon dioxide (with a corresponding increase in oxygen) concentration levels for a period of approximately 10 months. Finally, on approximately January 1, 2003, field gas levels return to those of the other cells.

Landfill Gas Composition for Cell 5.1 G01

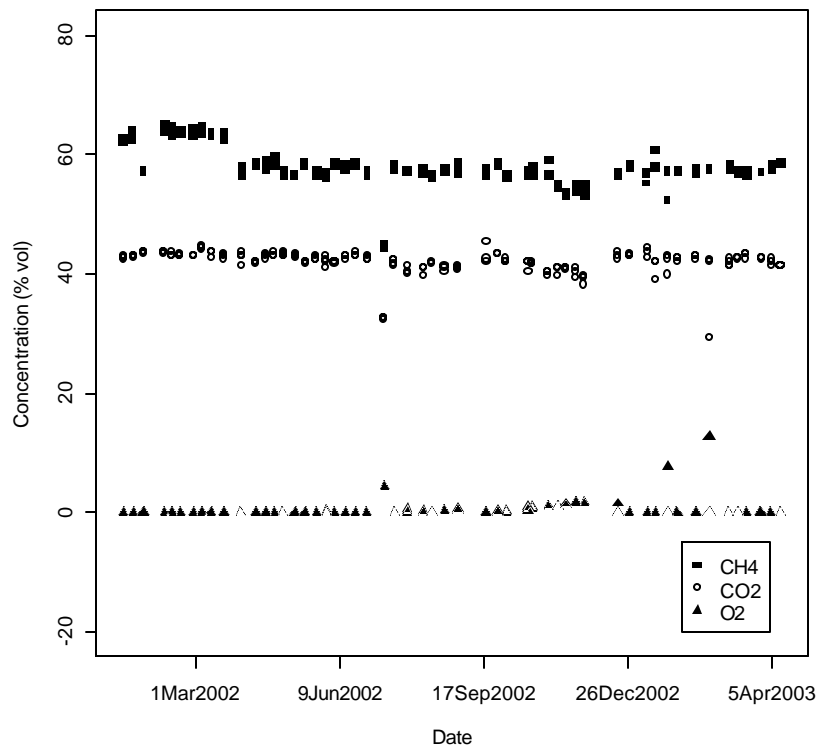


Landfill Gas Composition for Cell 5.2 G01

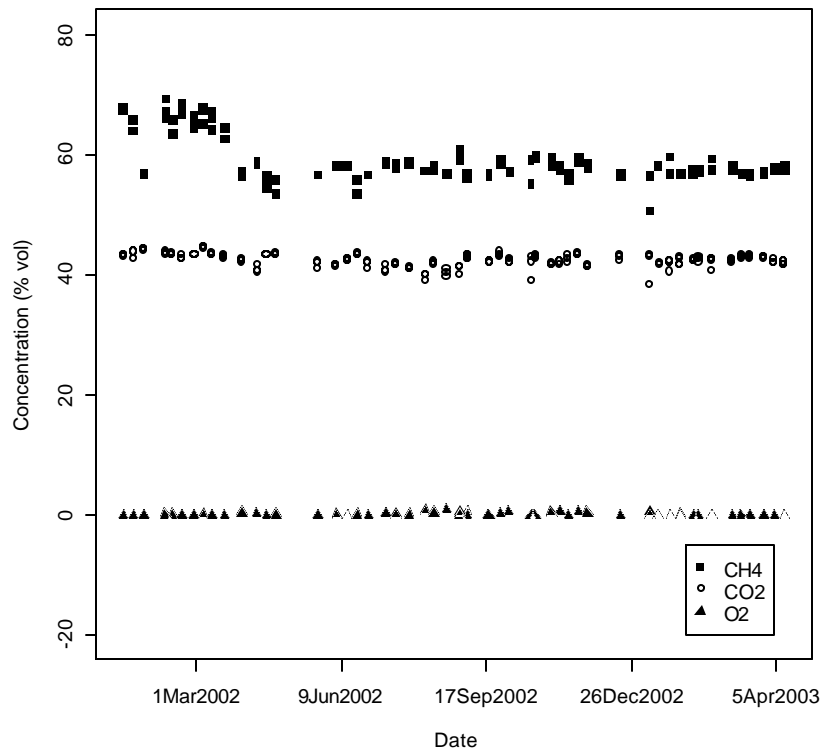


* 5.1=FLB cell 5S
5.2=FLB cell 5N

Landfill Gas Composition for Cell 7.3A G01

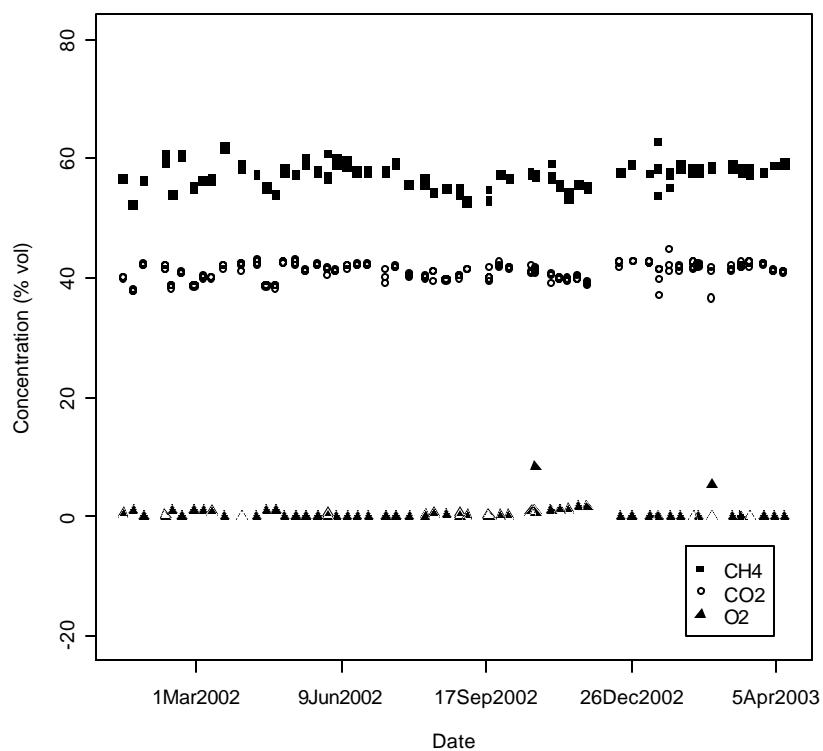


Landfill Gas Composition for Cell 7.3A G02

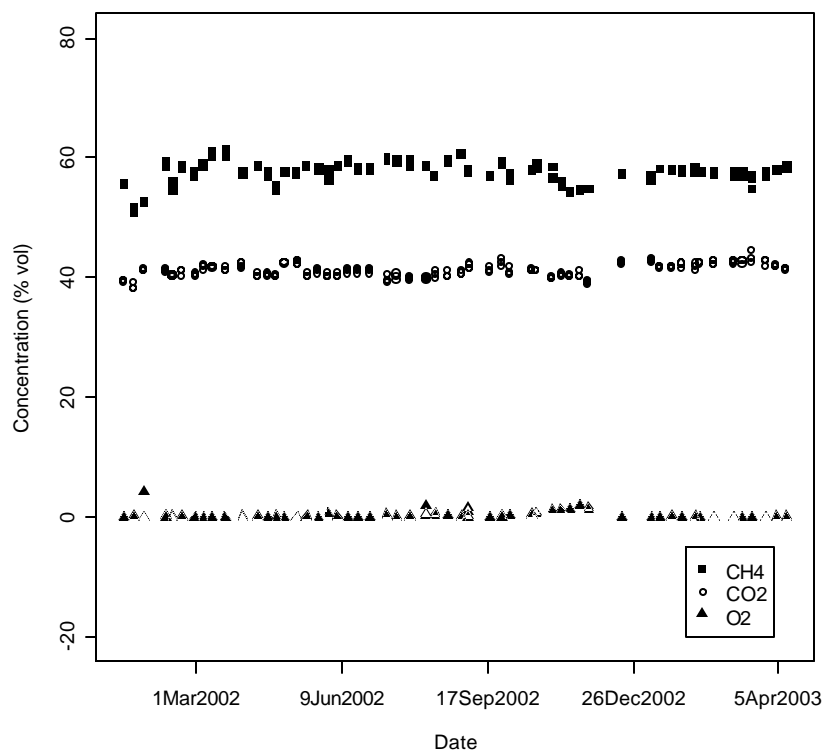


* 7.3=AALB cell 7.3

Landfill Gas Composition for Cell 7.3B G01



Landfill Gas Composition for Cell 7.3B G02



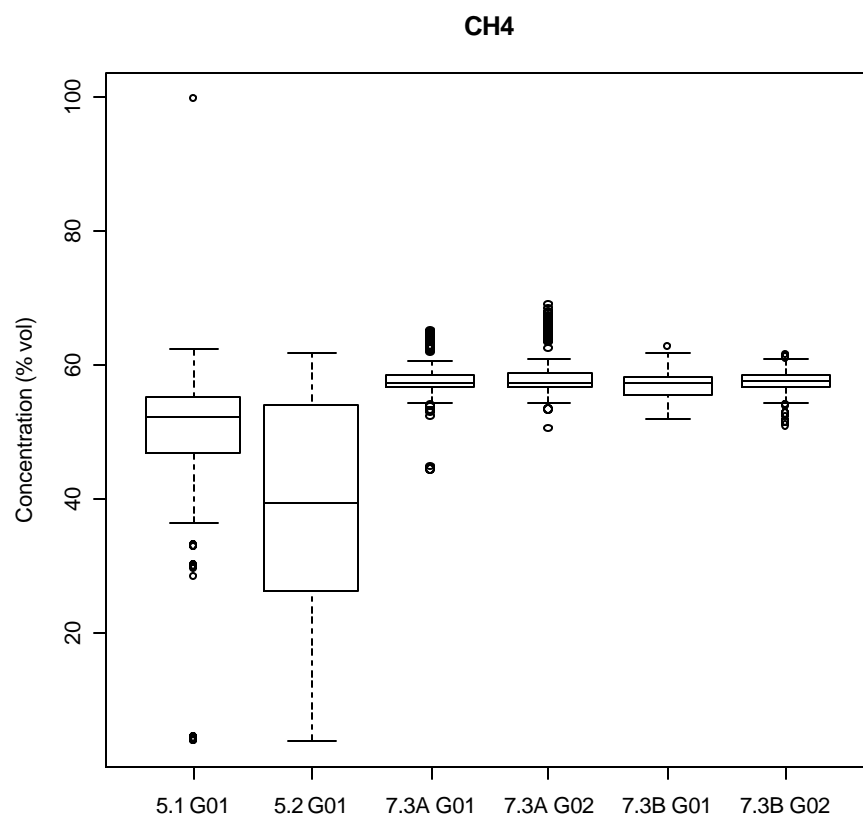
* 7.3=Control cell 7.3

FIELD GAS BOX-PLOTS

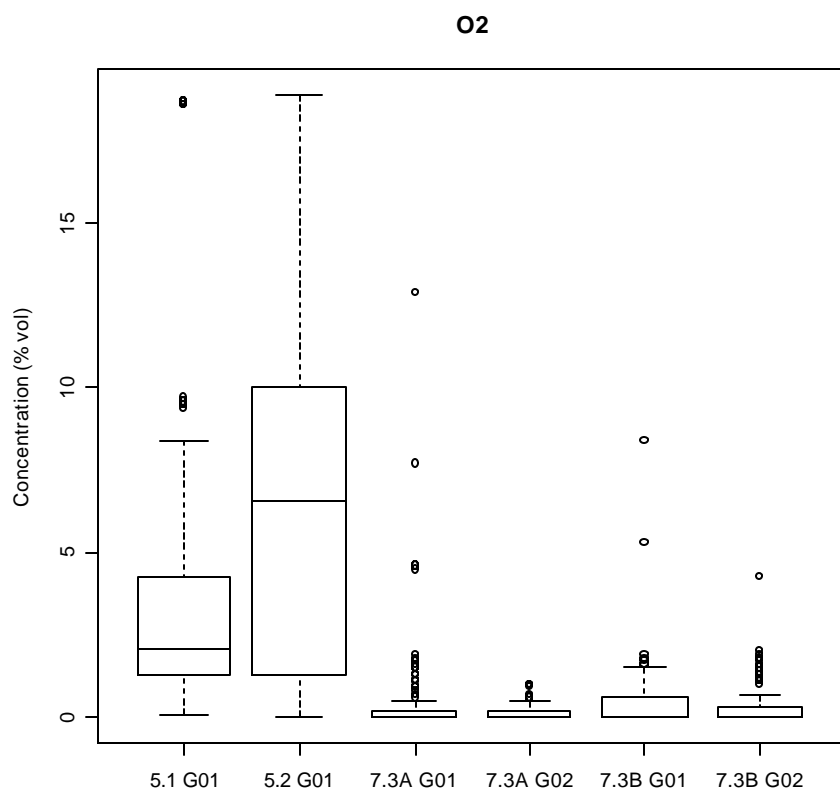
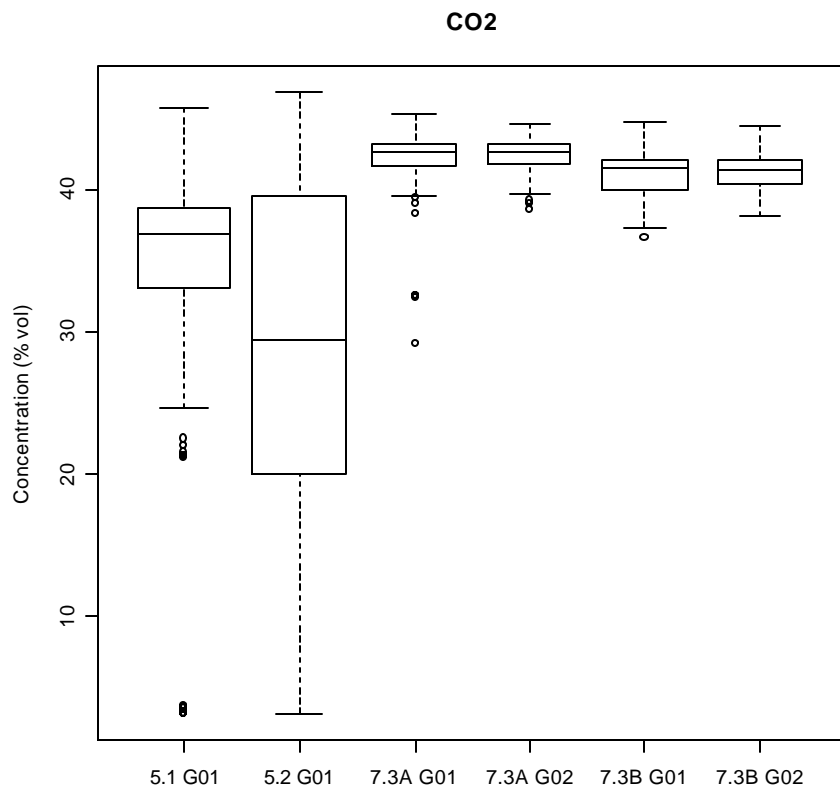
Summary

The first tool we use to investigate the dataset are boxplots, or box and whiskers plots. A box and whiskers plot is composed of a central box divided by a line and two lines extending out from the box called whiskers. The length of the central box indicates the spread of the bulk of the data (the central 50%) while the length of the whiskers show how stretched the tails of the distribution are. The width of the box has no particular meaning; the plot can be made quite narrow without affecting its visual impact. The sample median is displayed as a line through the box. Any unusually small/large data points are displayed by a circle on the plot. A box and whiskers plot can be used to assess the symmetry of the data. If the distribution is symmetrical, then the box is divided in two equal halves by the median, the whiskers will be the same length and the number of extreme data points will be distributed equally on either end of the plot. A boxplot is a way to visually analyze a dataset's distribution. The 25th and 75th quantile are the endpoints that encompass the filled box. The whiskers extend out to the largest(smallest) data points that lie more than 1.5 times the interquartile range (IQR, the 75th quantile minus the 25th quantile) on each side of the median, a common non-parametric measure to distinguish possible outliers. Potential outliers are then plotted as circles outside of this range. These plots are very useful in making general decisions regarding the distributional form of the data. For example, assumptions of normality imply symmetrical data and if the data do not appear symmetric according to the boxplots there will most likely be problems with assuming normality.

The box-plots for the three field gases demonstrate that the FLB cells contain slightly smaller concentrations of methane and carbon dioxide overall and slightly higher concentrations of oxygen. Also, the control cells contain far less variability in concentration levels. FLB cell 5.2 has a larger variability because of the 10 month decrease in methane and carbon dioxide levels (10 month increase in oxygen levels).



*5.1(2) : *FLB* Cell 5.1(2) 7.3 : *Control* Cell 7.3



*5.1(2) : *FLB* Cell 5.1(2) 7.3 : *Control* Cell 7.3

TREND TESTS

Summary

The Mann-Kendall results must be considered with caution. Well-constructed data sets will be evenly collected over time and must not exhibit any obvious temporal correlation. Both of the assumptions seem to be violated by the data in areas, particularly temporal correlation. Therefore, the results here are strictly qualitative and hopefully will help the reader reconstruct the statistical nature of the data. The Mann-Kendall test attempts to test for the existence of a trend by comparing the signs of pair-wise differences in the data. The null hypothesis is that there is no trend. In our case, the alternative is that there exists a trend, *either positive or negative*. A low p-value will reject “randomness” in favor of the existence of a trend. Further information can then be extracted by viewing the slope estimates. For n data points, the slope estimate is created by computing the $n(n-1)/2$ different slopes estimates between individual points and then selecting the median as the overall estimate. Details can be found in Hollander & Wolfe, pp 416-420, 1973.

LEACHATE – Mann-Kendall Test

*p-values (values below 0.05 in **bold**)*

Cell	BOD	COD	Ammonia (As N)	Total Kjeldahl Nitrogen (TKN)	Phosphorous, Total
Control cell 7.3A	0.112	1	0.922	0.108	0.697
Control cell 7.3B	0.0372	0.576	0.0252	0.0635	0.441
AALB cell 7.4A	0.035	0.029	0.127	1	0.0134
AALB cell 7.4B	0.0000817	0.00114	0.0529	0.806	0.127
FLB cell 5.1A	0.337	0.607	0.0399	0.00915	0.627
FLB cell 5.1B	0.000958	0.0122	0.0907	0.251	0.00591
FLB cell 5.2A	0.000246	0.381	0.000147	0.108	0.0512
FLB cell 5.2B	0.291	0.131	0.00152	0.0476	0.952

Slope Estimate

(change/day, pos. in red, neg. in blue, significant slopes “grayed”)

Cell	BOD	COD	Ammonia (As N)	Total Kjeldahl Nitrogen (TKN)	Phosphorous, Total
------	-----	-----	-------------------	----------------------------------	-----------------------

Control cell 7.3A	-0.0628	0.00208	0.0234	-0.641	0.00016
Control cell 7.3B	-0.502	-0.593	0.6	-0.3	0.00256
AALB cell 7.4A	5.79	9.28	0.785	-0.267	0.0123
AALB cell 7.4B	-17.1	-20	1.66	-1.58	0.00803
FLB cell 5.1A	-0.0631	0.167	-1.58	-3.75	0.000789
FLB cell 5.1B	-0.23	-1.67	-1.14	-2.94	0.005
FLB cell 5.2A	-0.411	-1.76	-2.37	-4.7	-0.00683
FLB cell 5.2B	-0.0764	-0.476	-1.03	-3.5	0.000152

FIELD GAS – Mann-Kendall Test

p-values (values below 0.05 in bold)

Cell	CH4	CO2	O2
Control cell 7.3A G01	1.481e-08	2.387e-08	0.0137
Control cell 7.3A G02	4.613e-06	0.0006	0.4653
Control cell 7.3B G01	0.0559	0.0100	0.0022
Control cell 7.3B G02	0.1992	1.179e-08	0.1485
FLB cell 5.1 G01	0.0853	0.0385	0.0391
FLB cell 5.2 G01	0.0037	0.0010	0.0004

Slope Estimate

(change/day, pos. in red, neg. in blue, significant slopes “grayed”)

Cell	CH4	CO2	O2
Control cell 7.3A G01	-0.006667	-0.003187	0.000000
Control cell 7.3A G02	-0.006452	-0.001832	0.000000
Control cell 7.3B G01	0.002083	0.001875	0.000000

Control cell 7.3B G02	-0.001049	0.003704	0.000000
FLB cell 5.1 G01	-0.005424	-0.004786	0.001550
FLB cell 5.2 G01	-0.021591	-0.014725	0.007919532

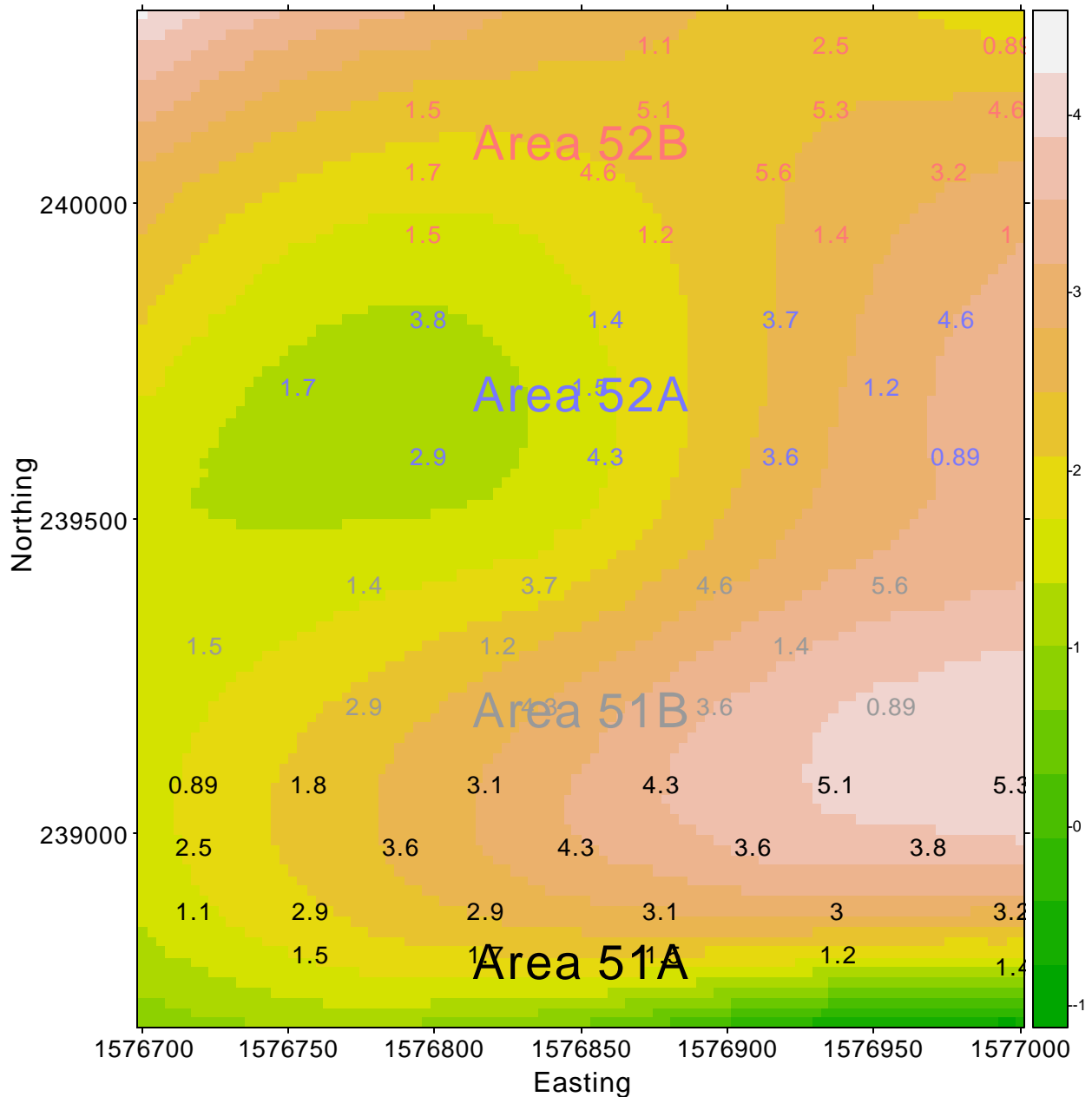
Interpretation

A good example to start with is the AALB 7.4 data, which appears to be trended strongly for both ‘replicates’ in most parameters that were analyzed. A review of the time plots shows that this indeed seems to be the case and regardless of any violations of the assumptions, there appears to be trends present. This is most likely a function of the relatively young age of the landfill cell. FLB cell 5.1B illustrates some of the hazards of applying a simple trend test to data that shows serial correlation. There does not seem to be an overall positive/negative trend for most parameters but it appears that a trend exists according to the test. This could be caused by the obvious temporal correlation in the data and the fact that this is normally a major violation of the Mann Kendall assumptions. If this correlation continues to be evident with increased data then a time series model will most likely need to be fitted to the data in order to remove the temporal correlation that is being seen. Although it is possible, it is somewhat premature at this point to assume a model structure for the many of these parameters given only a couple of years of data. The heterogeneous nature of the patterns seen (in the time leachate plots) do not yet give rise to a common model that will be needed to make comparisons.

SETTLING DATA

Levelplot of Settling Height in FLB Cell

(7/01/2001 thru 6/1/2003)



NOTE:

The procedure for this analysis is as follows. A local multi-variate regression model is fit to the spatial parameters (Easting and Northing). The local least squares criterion is then minimized to produce estimates of the coefficients, and the resulting plane estimate from which the estimate at the point is created. The procedure is repeated for each point of estimation. The amount of smoothing that is done to the data is highly dependent upon the value of h chosen. A large bandwidth h leads to a lot of smoothing since many data points are used in the smoothing. A small h leads to a very noisy estimate since only points right in the vicinity of the fitting point are being used for the estimate. In this model, the variable bandwidth h represents a nearest-neighbor based bandwidth that utilizes the closest 50% of the data points

which is a somewhat average bandwidth.

Care must be taken in interpreting these plots. First and foremost, the map is only really applicable within the confines of the sampling, the area in which the sampling was done. In addition to this, it must be realized that smoothing estimates near the edge of the sampled area may not be as reliable as those near the middle. Confidence bounds on the contours were not attempted here and would probably take a serious effort to create, assuming we could find a method for which the assumptions were satisfied.

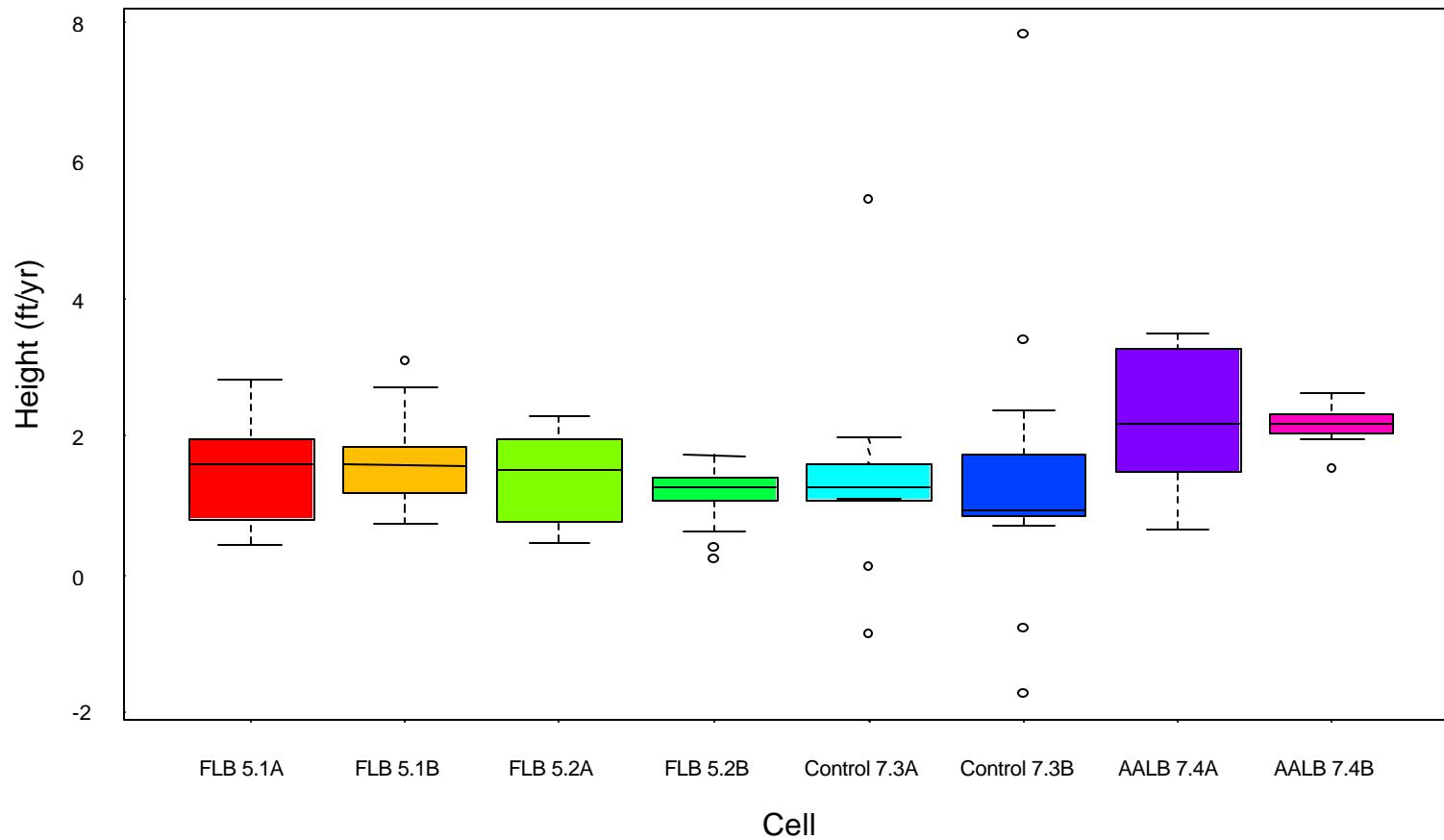
Summary of FLB cell 5.1/FLB cell 5.2 Levelplot

Settling heights do not appear to be strongly correlated although there does appear to be some mild correlation. A few anomalies seem to exist, one in particular in the east section of Area FLB cell 5.1B where there is a 1.4 ft. and a 0.89 ft. result that are amidst much higher results. Bigger differences seem to exist towards the center/east portions of the cells. As more data becomes available, it may be useful to attempt other modeling strategies.

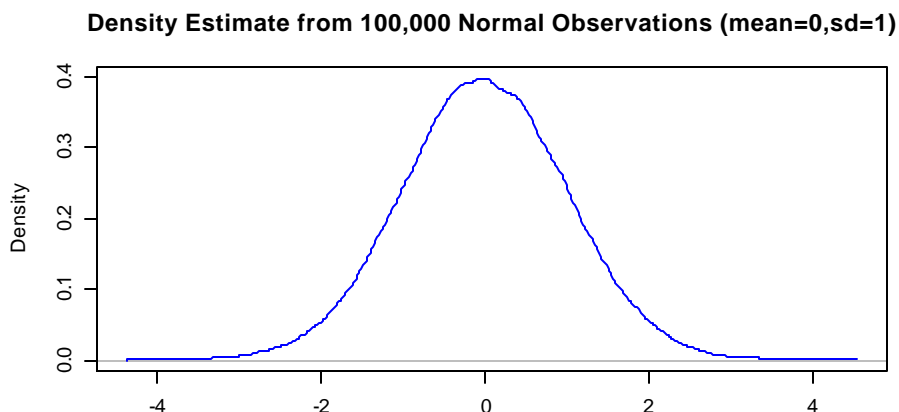
The data available for settling in Control cell 7.3 and AALB cell 7.4 was too sparse and discontinuous to warrant a spatial smoothing plot. We hope that in future the data collected will be less impacted by earth moving equipment and perhaps give us additional insight into the spatial nature of the settling in the control and ALLB cells.

Boxplot of Mean Annual Differences in Height

An explanation of what a *boxplot* is can be found in the previous section on FIELD GAS BOX PLOTS.



A formal definition of *normality* can be found in any introductory statistics book. For our purposes, one can assume we are testing for the special ‘bell’ shape that defines it (empirical density estimate from Normal distribution shown below).



According to the Shapiro Wilk (*Patrick Royston, Algorithm AS 181: The W Test for Normality. Applied Statistics, 31, 176-180, 1982*) normality test results shown below, the data doesn’t seem to deviate too far from normality. There are two rejections of normality out of the eight data sets. When reviewing the boxplots of these two cases, one can see that both are *skewed* upward, indicated by the median being less than halfway up the main boxplot body. However, there are two others that would be rejected if the significance level was 0.10 instead of 0.05. Overall, this is not a strong case for normality.

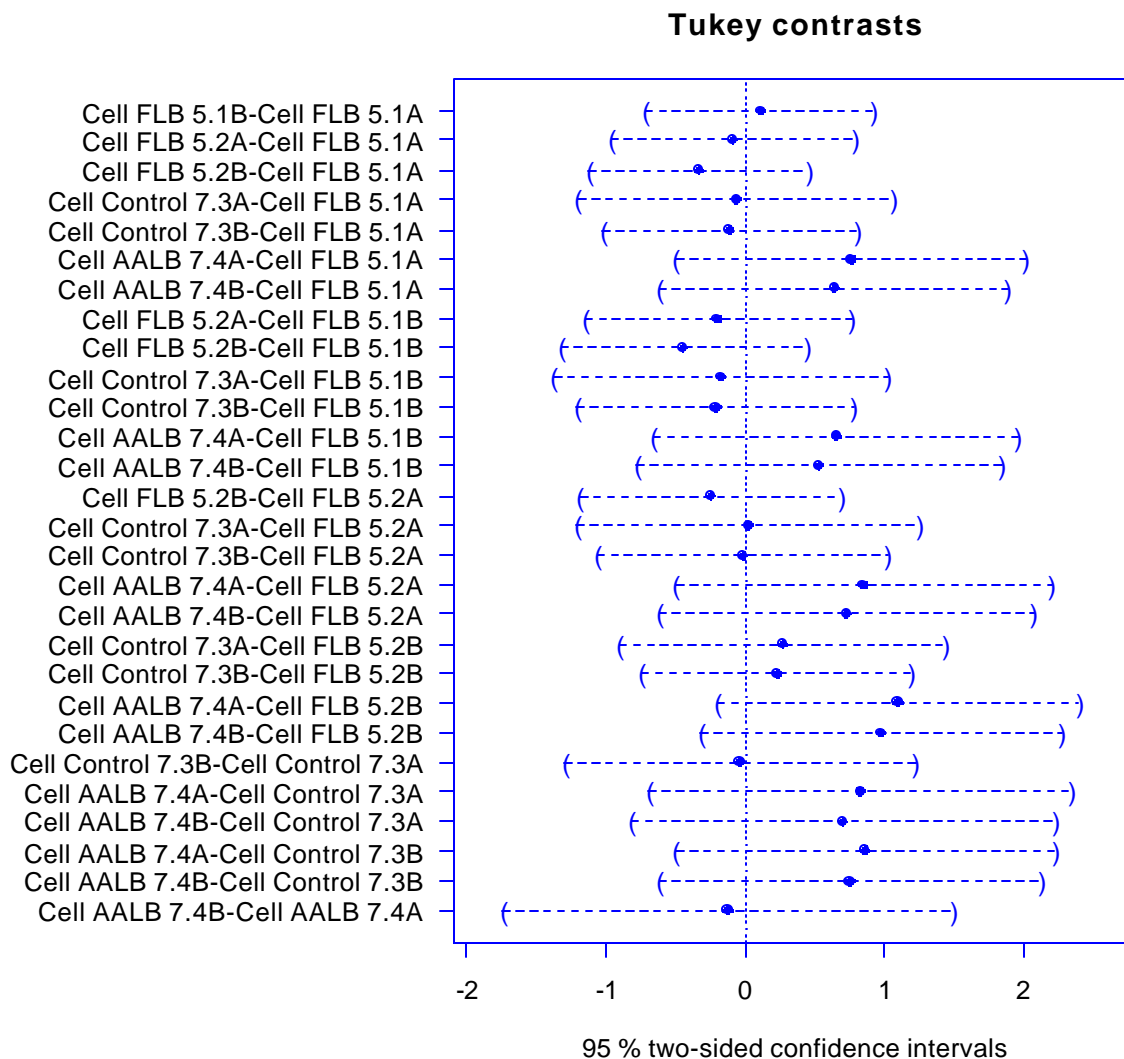
Shapiro Wilk Normality Test

Cell	FLB 51A	FLB 51B	FLB 52A	FLB 52B	Control 73A	Control 73B	AALB 7.4A	AALB 74B
p-value	0.077	0.246	0.145	0.064	0.049	0.001	0.356	0.872

Given this, we will include two analyses of differences between the eight sets. First, a Tukey multiple comparison test will be performed giving 95% two-sided confidence intervals for each pair-wise difference of means. The multiple comparison procedure accounts for the fact that multiple comparisons are being performed and adjusts the confidence intervals accordingly.

As one can see by reviewing the graph above, every confidence interval contains zero and therefore we can’t reliably conclude that there is a difference between any of the settling cell data sets. The cell that appears closest to being distinguished is cell AALB cell 7.4. However, earth activity caused a large portion of the data to be ignored, which lowered the sample size for this cell and could have had some effect upon the analyses. In addition to this, the large number of comparisons required in conjunction with the

multiple comparison approach, makes it very difficult for the test to show a significant difference.



Since this procedure depends upon the normality of each individual data set, we will also include some simple non-parametric pair-wise comparisons, which do not necessarily account for the multiple comparisons. In lieu of being a multiple comparison procedure, they should still provide additional evidence for the analysis. In particular, the Wilcoxon Rank Sum Test tests for a difference between the locations of two similarly shaped distributions. The null hypothesis is that the two variables, for instance FLB cell 5.1B and FLB cell 5.1A, have the same *unspecified* probability distribution. The alternative is that one variable tends to be *larger/(smaller)* than the other. A common way to visualize this is that one variable's distribution is the same as the other except shifted to the left (smaller) or right (larger). Therefore, an assumption of the test is that both variables' distributions are similarly shaped, which can't be stated conclusively here and upon further review might even be stated as unlikely. Nevertheless, it provides a bit more support for what we see in the boxplots.

Individual Wilcoxon Rank Sum Tests

Cell Difference	p-value	
FLB cell 5.1B-FLB cell 5.1A	0.631	
FLB cell 5.2A-FLB cell 5.1A	0.717	
<i>FLB cell 5.2B-FLB cell 5.1A</i>	<i>0.016</i>	The Wilcoxon Rank Sum Tests seem to pull out AALB cell 7.4B in particular as one with increased settling differences, relative to the others. However, there is a large difference in running these non-parametric tests individually (<i>not as a multiple comparison</i>) and the confidence level of the overall set of comparisons would be much lower than that of the Tukey multiple comparison test. This is far from conclusive evidence, however, qualitatively with all evidence combined, it does appear that AALB cell 7.4B does exhibit larger settling values in general.
Control cell 7.3A-FLB cell 5.1A	0.323	
Control cell 7.3B-FLB cell 5.1A	0.296	
AALB cell 7.4A-FLB cell 5.1A	0.131	
<i>AALB cell 7.4B-FLB cell 5.1A</i>	<i>0.014</i>	
FLB cell 5.2A-FLB cell 5.1B	0.527	
<i>FLB cell 5.2B-FLB cell 5.1B</i>	<i>0.006</i>	
Control cell 7.3A-FLB cell 5.1B	0.349	
Control cell 7.3B-FLB cell 5.1B	0.057	
AALB cell 7.4A-FLB cell 5.1B	0.199	
<i>AALB cell 7.4B-FLB cell 5.1B</i>	<i>0.013</i>	
FLB cell 5.2B-FLB cell 5.2A	0.166	
Control cell 7.3A-FLB cell 5.2A	0.554	
Control cell 7.3B-FLB cell 5.2A	0.501	
AALB cell 7.4A-FLB cell 5.2A	0.125	
<i>AALB cell 7.4B-FLB cell 5.2A</i>	<i>0.012</i>	
Control cell 7.3A-FLB cell 5.2B	0.907	
Control cell 7.3B-FLB cell 5.2B	0.291	
<i>AALB cell 7.4A-FLB cell 5.2B</i>	<i>0.007</i>	
<i>AALB cell 7.4B-FLB cell 5.2B</i>	<i>0.000</i>	
Control cell 7.3B-Control cell 7.3A	0.445	
AALB cell 7.4A-Control cell 7.3A	0.138	
<i>AALB cell 7.4B-Control cell 7.3A</i>	<i>0.026</i>	
AALB cell 7.4A-Control cell 7.3B	0.102	
<i>AALB cell 7.4B-Control cell 7.3B</i>	<i>0.021</i>	
AALB cell 7.4B-AALB cell 7.4A	0.949	

OUTER LOOP LANDFILL BIOREACTOR DATA

This document summarizes the data that Neptune has received to date from WMI and/or EPA/NRMRL. The data fall into 4 groups which might be labeled:

1. Leachate (monthly and quarterly data collected from all disposal cells)
2. Solids (weekly data collected from the control and FLB cells)
3. Landfill Gas (quarterly data collected from the control and FLB cells)
4. Field Gas (weekly data collected from the control and FLB cells)

The disposal cells have been labeled somewhat differently in the data files received. We will use the following denotation:

- A. 73A and 73B – two control disposal cells
 - B. 74A and 74B – two AALB treatment disposal cells
 - C. 51A, 5 S-, 52A, 52B – four FLB treatment disposal cells
1. The leachate data are labeled this way with an “L01” extension.
 2. The solids data are labeled this way for the control disposal cells with extensions that identify specific locations (e.g., 7.3A-1). For the FLB treatment cells, the solids data have been labeled 5N-x and 5S-x indicating north and south disposal cells and with x denoting a specific location. The locations also indicate which FLB treatment disposal cell applies: x in the range 1-6 for 5N implies 52B, in the range 21-26 for 5N implies 52A; x in the range 1-6 for 5S implies 51A, in the range 21-26 for 5S implies 5 S-. Locations for the solids data have been provided for the FLB treatment and control cells in terms of (x,y) coordinates in hard copy form and have been entered electronically into the database.
 3. The landfill gas data are labeled 73A and 73B for the control cells. For the FLB treatment cells the labels are 51 and 52, implying that landfill gas data were not collected on a more refined level (e.g., 51A and 5 S- separately), with an extension of “G01”.
 4. The field gas data are labeled 73A and 73B for the control cells. For the FLB treatment cells the labels are 51 and 52, implying that landfill gas data were not collected on a more refined level (e.g., 51A and 5 S- separately), with an extension of “G01” or “G02”.

One other attribute of the data that will be relevant for data analysis is the temporal information. Different data were collected at different times and with different periodicity, as follows:

1. The leachate data were provided in 27 data files that cover the following dates, with the corresponding number of data rows in each file:

6/1/01 – (615)	6/25/01 – (801)	6/26/01 – (615)
7/11/01 – (1042)	7/12/01 – (188)	11/15/01 – (1217)
12/17/01 – (36)	12/18/01 – (86)	1/10/02 – (120)
2/11/02 – (120)	3/19/02 – (752)	3/20/02 – (1067)
4/11/02 – (106)	4/12/02 – (24)	5/13/02 – (63)
5/14/02 – (61)	6/10/02 – (1603)	7/16/02 – (120)
8/7/02 – (128)	9/16/02 – (1553)	10/21/02 – (128)
11/14/02 – (128)	12/16/02 – (1408)	1/22/03 – (113)
2/12/2003 – (121)	3/18/03 – (1552)	4/10/03 – (120)

The number of data points in each data set depends on the number of parameters measured. The leachate data are recorded monthly for some parameters and quarterly for many more. Hence, when the number of data rows is around 1,000, the data include quarterly results (7/11/01, 11/15/01, 3/20/02, 6/10/02, 9/16/02, 12/16/02, and 3/18/03). The data from June 2001 represent the first rounds of data collected. It appears as though the data collection regime has stabilized since that time, and that more recent data have been collected on a more regular schedule.

2. The solids data are available for 4 days a week in each full week of the month of June 2000. In general, only one or two of those days were used to sample solids from a given location in a given disposal cell (for example, 18 samples were taken from location 73A-1 on 6/6/00, 6 samples were taken from 5N21 on 6/22/00). Samples were taken at each 3 inch depth interval, presumably to the bottom of the samples location bore hole. In total, 171 data points are available from 25 locations from the FLB treatment and control disposal cells.
3. The landfill gas data have been collected quarterly in the following months or dates (with number of data rows in parentheses):

12/19/01 – (178)	3/21/02 – (453)	6/13/02- 6/28/02 – (466)
------------------	-----------------	--------------------------

Only a few samples have been collected in each case (e.g., 2 samples on 12/19/02, 6 samples on 3/21/02, and 6 samples on June 2002).

4. The field gas data have been collected approximately weekly since 11/16/01 for the FLB treatment disposal cell, and from 1/10/02 for the control disposal cell. For the control cells approximately 6 samples are included weekly for each cell (73A and 73B). There are a total of 687 data rows for this cell. For the FLB treatment disposal cells approximately 3 samples are included weekly for cell 51 and again for cell 52. There are a total of 207 and 208 data rows for cell 51 and for cell 52, respectively.

APPENDIX E

SURFACE EMISSIONS, REMOTE MONITORING STUDIES

SURFACE EMISSIONS, REMOTE MONITORING STUDIES

Prepared for:

U.S. Environmental Protection Agency
Air Pollution Prevention and Control Division
Air Pollution Branch
Research Triangle Park, NC 27711

Contract No. 68-C99-201
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Prepared by:

ARCADIS-Geraghty and Miller
P.O. Box 13109
Research Triangle Park, North Carolina 27709

September 16, 2003

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Fugitive Gas Emission Measurements

Landfill gas emissions have been found to be a concern to human health and the environment due to the explosive potential of the gas, emissions of hazardous air pollutants (HAPs) and volatile organic compounds (VOCs), emissions of methane that contribute to climate change, and odor nuisance associated with landfill gas. Landfills emit more than 100 nonmethane organic compounds (NMOCs) (EPA 1997 a and b). The majority of the NMOCs are VOCs which contribute to urban smog. Over thirty of the landfill gas NMOCs are classified as HAPs (EPA 2003). As a result, landfills are listed as a source as part of the Urban Air Toxic Strategy.

Due to the concerns for human health and the environment, Clean Air Act (CAA) regulations have been promulgated that require landfill gas collection and control at landfills that (1) contain at least 2.5 million megagrams (Mg) or 2.5 million cubic meters of waste and (2) emit 50 Mg per year or more of NMOCs (EPA, 1998). The landfill evaluated in this study has gas collection and control and a portion of the gas is used at a near-by industrial plant as boiler fuel (offsetting fossil fuel). The measurements presented in this section are part of a larger effort by EPA's Office of Research and Development to obtain necessary data needed to update the existing set of landfill gas emissions factors (Thorneloe, 2003). These data will also be used to update the existing set of landfill gas emission factors and as input to the evaluation of residual risk from MSW landfills as required by CAA Section 112 (f).

Fugitive gas emissions are those emissions that are not captured for collection and control. Differences in how a site may be operated can contribute to the level of fugitive emissions. Optical remote sensing (ORS) was used to evaluate fugitive gas emissions for the retrofit and as-built bioreactors. Fugitive gas emissions have been identified as a potential concern because of the rapid increase in emissions when wet or bioreactor landfills are operated. The data collected through these field test measurements will help to evaluate these concerns and hopefully provide needed data to compare emissions from the as-built and retrofit bioreactors to the control site. Measurements were also conducted at the biocover units (where compost is used as a cover material) and compost facility.

At least 3 rounds of fugitive emissions testing are being conducted at this site to help evaluate any increase or decrease in emissions from bioreactors (as compared to conventional landfilling practice). This section provides the results from the first round of testing. The second and third rounds will be completed by the fall of 2003 with results available by spring of 2004. The data resulting from these field tests will be used along with other available data from operating bioreactors to update existing EPA emissions factors. Current factors do not consider operation under wet or bioreactor conditions. Sites that are not subject to CAA regulations either due to their size or mass emission rate are not required by federal regulations to collect and control landfill gas emissions. There has been a marked increase in interest and operation of landfills with leachate recirculation and other liquid additions. Many of these sites do not have gas collection and control. Data from this site will help to provide data needed to estimate emissions at sites without controls in place and determine what level of fugitives may exist for this type of operation.

Data from this site will also be used in EPA's MSW Decision Support Tool (DST) to quantify total emissions for both conventional and bioreactor operations to help provide perspective of the total emissions released to the environment over the length of time that emissions are released.

(Thorneloe, 2003) Offsets for landfill gas energy utilization will be accounted for along with emissions associated with the design, construction, operation, and monitoring of the landfill. The result will be an evaluation of the life-cycle environmental tradeoffs to compare wet landfills versus conventional landfills.

Figure 1 identifies each of the areas included in this study. The following tasks were conducted in September 2002 for the as-built and retrofit bioreactors and the control, bio-cover, and composting facility:

- Conduct background measurements using the bistatic open path-Fourier Transform Infrared Spectroscopy (OP-FTIR).
- Collect OP-FTIR data in order to identify major emissions hot spots by generating surface concentration maps in the horizontal plane using OP-FTIR spectrometer;
- Conduct vertical scans to determine the emission fluxes of detectable compounds downwind from major hot spots
- Collect ancillary data needed for calculating mass emissions rates for pollutants of concern including methane, VOCs, and HAPs. Data for ammonia emissions were collected for the compost facility and other areas.
- The following sections present an overview of:
 1. Optical remote sensing and calculation of emission flux;
 2. Data quality objectives and criteria;
 3. Round 1 field activities and data collection/analysis;
 4. Data Quality Assurance and Control; and
 5. Conclusions.

Optical Remote Sensing and Overview of Calculation of Emission Flux

The application of optical remote sensing (ORS) to quantify fugitive gas emissions has seen dramatic improvements over the last year partly due to the partnership between EPA's Emissions Measurement Center and the National Risk Management Research Laboratory (NRMRL). In addition, EPA's Environmental Technology Initiative has tested different instrument types to provide additional validation of new ORS instruments. Because of the advancements made with this technology, the Agency recommends that this be used for evaluating large area sources. ASTM procedures are available for application of open-path Fourier Transform Infrared (OP-FTIR) (ASTM E 1865-97, Re-approved 2002). The EPA's Emissions Measurement Center is working to develop an EPA test method for ORS to be available by fall 2004.

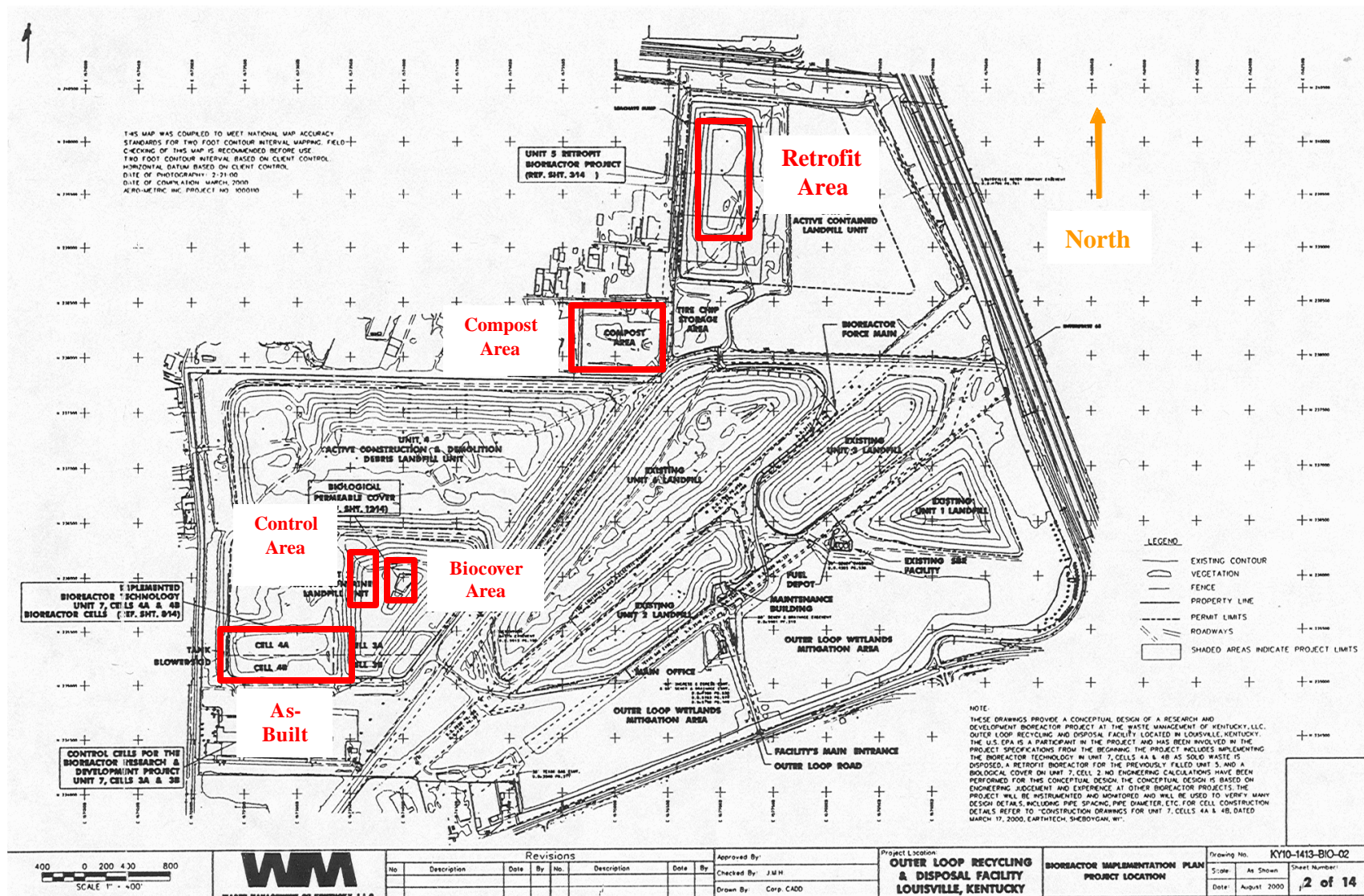


Figure 1. Waste Management, Inc. Outer Loop Facility Louisville, KY

The ORS improvements include an innovative method [Yost and Hashmonay, 2003] designed to obtain detailed spatial information from path-integrated ORD measurements by the use of optimization algorithms. The method uses a novel configuration of non-overlapping radial beam geometry to map the concentration distributions in a plane. This method, Radial Plume Mapping (RPM), is also applied to the vertical plane, downwind from the area source to map the crosswind and vertical profiles of a plume. The flux rate is calculated using wind data and other meteorological data. Measurements of any background emissions are also accounted for in these calculations through use of a bistatic Open-Path Fourier Transform Infra-red (OP-FTIR) instrument which can accurately measure the concentrations of a multitude of infrared absorbing gaseous chemicals with high temporal resolution. The chemical vapor, emitted from an emission source, forms a plume, which is carried by the wind across the multiple infrared beams. The beam measurements avoid some of the uncertainties that are inherent in the traditional point measurements. More information on these methods can be found in *Hashmonay and Yost [1999B]*, and *Hashmonay et al. [1999]*.

The OP-FTIR Spectrometer combined with the RPM method is designed for both fence-line monitoring applications, and real-time, on-site, remediation monitoring and source characterization. The OP-FTIR can be operated in either a monostatic, or bistatic configuration. In the monostatic configuration, an infrared light beam, modulated by a Michelson interferometer is transmitted from a single telescope to a retro reflector (mirror) target, which is usually set up at a range of 100 to 500 meters. The returned light signal is received by the single telescope and directed to a detector. The light is absorbed by the molecules in the beam path as the light propagates to the retro reflector and again as the light is reflected back to the analyzer. Thus, the round-trip path of the light doubles the chemical absorption signal.

In the bistatic configuration, the OP-FTIR detector, interferometer, and receiving optics are set up at one end of the path length being surveyed, and an infrared light source is set up at the other end of the path length. Generally, the path length is between 100 to 300 meters. In this configuration, light is absorbed by gas molecules as the light travels from the infrared source to the detector (once through the plume). The use of retro reflectors is not required when operating a bistatic OP-FTIR. A theodolite is used to make the survey measurement of the azimuth and elevation angles and the radial distances to the retro reflectors, relative to the OP-FTIR sensor.

Surface Radial Plume Mapping

This technique yields information on the two-dimensional distribution of the concentrations in the form of chemical-concentration contour maps (Hashmonay et al., 1999; Wu et al., 1999; Hashmonay et al., 2002). Horizontal radial scanning was performed with the ORS beams located as close to the ground as practical. This enhances the ability to detect minor constituents emitted from the ground, since the emitted plumes dilute significantly at higher levels above the ground. The survey area is divided into a Cartesian grid of 'n' times 'm' rectangular cells. A retro reflector is located in each of these cells and the OP-FTIR sensor scans to each of these retro reflectors, dwelling on each for a set measurement-time (30 seconds was used for this study). The system scans to the retro reflectors in the order of either increasing or decreasing azimuth angle. The path-integrated concentrations measured at each retro reflector are averaged over a several scanning cycles to produce time-averaged concentration maps. Meteorological measurements were made concurrent to the scanning measurements.

For the first stage of reconstructing the average cell concentrations, an iterative algebraic deconvolution algorithm is used. The path-integrated concentration (PIC), as a function of the field of concentration, is given by:

$$PIC_k = \sum_m K_{km} c_m$$

where K is a Kernel matrix that incorporates the specific beam geometry with the cell dimensions; k is the number index for the beam paths and m is the number index for the cells; and c is the average concentration in the m^{th} cell. Each value in the Kernel matrix K is the length of the k^{th} beam in the m^{th} cell; therefore, the matrix is specific to the beam geometry. To solve for the average concentrations (one for each cell) the Non Negative Least Squares (NNLS) was applied. The NNLS is similar to a classical least square optimization algorithm, but is constrained to provide the best fit of non-negative values. The NNLS algorithm was tested and compared to the relaxation multiplicative algebraic reconstruction technique (MART) program previously developed and used. Both algorithms gave very similar results when reached to the same maximal level of fit between the predicted PIC and the observed PIC but the NNLS was much faster. Therefore, the NNLS algorithm will be applied in this study. This iterative procedure proceeds until the difference of the criteria parameter between sequential steps drops below a very small threshold value (tolerance). Multiplying the resulted vertical vector of averaged concentration by the matrix K , yields the end vector of predicted PIC data.

The second stage of the plume reconstruction is interpolation among the nine points, providing a peak concentration not limited only to the center of the cells. We will use the triangle-based cubic interpolation procedure. To extrapolate data values beyond the peripheral cell centers and within the rectangle measurement domain, we will assign the concentration of each corner cell to the corresponding corner of the domain.

Figure 2 represents a typical horizontal RPM configuration. In this particular case, $n = m = 3$. The orange lines define the nine cells in the matrix. The blue lines represent the 9 optical paths, each terminating at a retroreflector (Hashmonay et al., 2002). The red spot represents a point source. The enclosed areas represent the calculated plume, transported downwind by the wind. The numbers associated with the contour lines (isopleths) are the determined values for the concentrations.

Vertical Scanning

The RPM method maps the concentrations in the plane of the measurement. By scanning in a vertical plane downwind from an area source, plume concentration profiles can be obtained, and plane-integrated concentrations can be calculated. The Smooth Beam Function Minimization (SBFM) reconstruction approach is used with a two-dimensional smooth basis function (bivariate Gaussian) in order to reconstruct the smoothed mass equivalent concentration map. The smoothed mass equivalent concentration map is reconstructed using *Matlab* (MathWorks). In the SBFM approach, a smooth basis function is assumed to describe the distribution of concentrations, and the search is for the unknown parameters of the basis function. Since our interest is in the plane integrated concentration and not the exact map of concentrations in the plane, we fit only one smoothed basis function (one bivariate Gaussian) to reconstruct the smoothed map.

Dislocation Distance = 2.4 m; CCF = 1.0

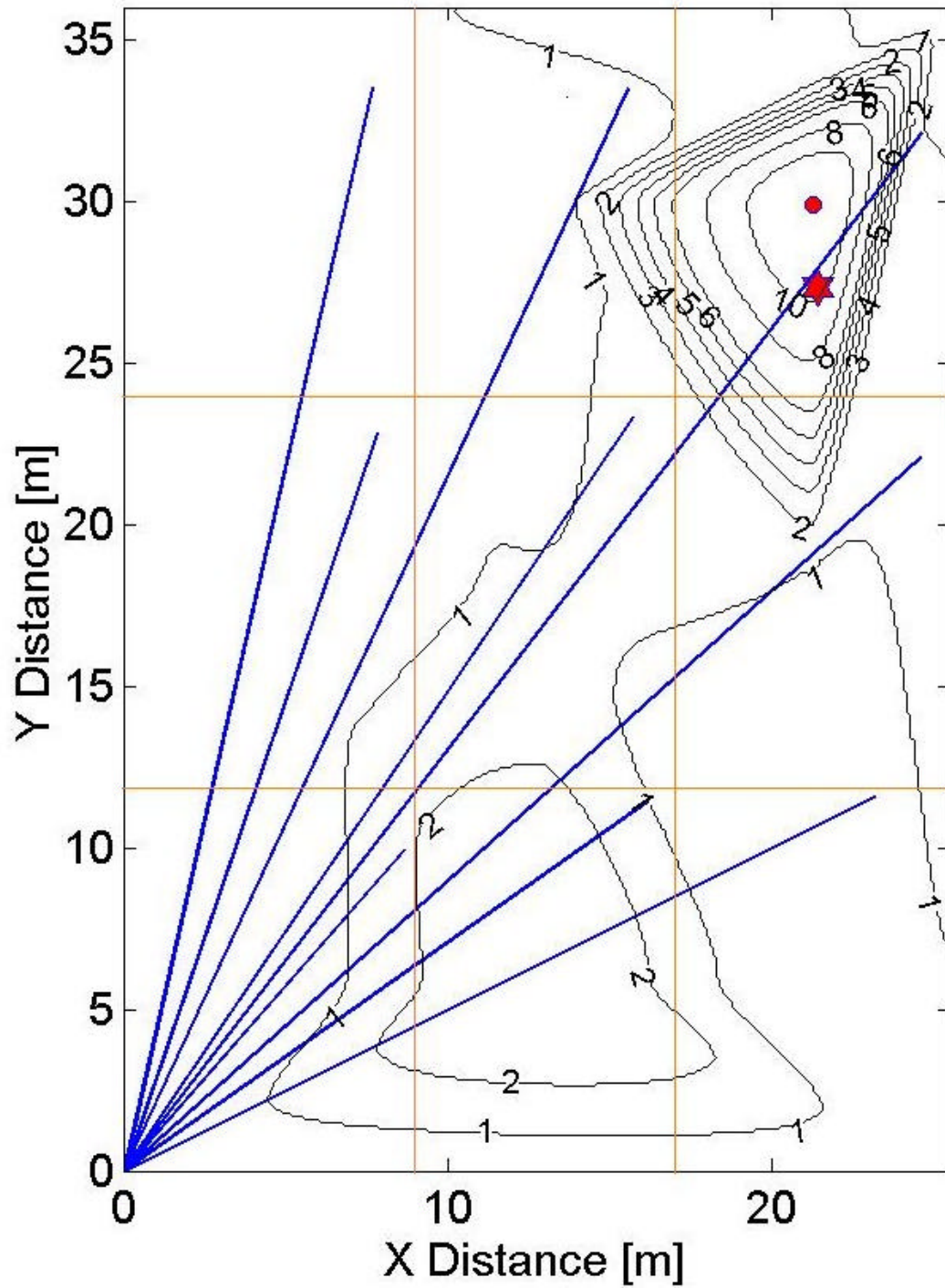


Figure 2. Example of a Typical Radial Scanning Configuration

However, this methodology does not assume that the true distribution of concentration in the vertical plane is a bivariate Gaussian. Earlier computational studies showed that one might fit a single bivariate Gaussian function to many kinds of skewed distributions and still retrieve a reasonably good estimate of the plane-integrated concentration. The fit of a single bivariate Gaussian function to a multiple mode distribution was also examined and found that the reconstructed plane integrated concentration conserved fairly well the test input plane integrated concentration.

In each iterative step of the SBFM search procedure, the measured PIC values are compared with assumed PIC values, calculated from the new set of parameters. In order to compute the assumed PIC values, the basis function is integrated along the beam path's direction and path-length.

In our beam geometry, it is convenient to express the smooth basis function G in polar coordinates r and φ .

$$G(r, \varphi) = \frac{A}{2\pi s_y s_z \sqrt{1-r_{12}^2}} \exp \left\{ -\frac{1}{2(1-r_{12}^2)} \left[\frac{(r \cdot \cos \varphi - m_y)^2}{s_y^2} - \frac{2r_{12}(r \cdot \cos \varphi - m_y)(r \cdot \sin \varphi - m_z)}{s_y s_z} + \frac{(r \cdot \sin \varphi - m_z)^2}{s_z^2} \right] \right\}$$

The bivariate Gaussian has six unknown independent parameters:

- A - normalizing coefficient which adjusts for the peak value of the bivariate surface
- \tilde{n}_{12} - correlation coefficient which defines the direction of the distribution-independent variations in relation to the Cartesian directions y and z ($\tilde{n}_{12}=0$ means that the distribution variations overlap the Cartesian coordinates)
- m_y and m_z - peak locations in Cartesian coordinates
- and σ_y and σ_z - standard deviations in Cartesian coordinates. To fit the unknown parameters of the smooth basis function to the PIC data, one has to define an error function for minimization.

The Sum of Squared Errors (SSE) function is defined in our study as:

$$SSE(A, r_{12}, m_y, m_z, s_y, s_z) = \sum_i \left(PIC_i - \int_0^{r_i} G(r, \varphi, A, r_{12}, m_y, m_z, s_y, s_z) dr \right)^2$$

Where PIC represents the measured PIC values and the index i is for the different beams. The SSE function is minimized using an iterative minimization procedure, such as the Simplex method, to solve for the unknown parameters. These calculations are performed using **MatLab** (MathWorks).

To obtain the plane-integrated concentration, we fit a bivariate Gaussian surface to match the volume under the underlying true concentration distribution surface. This volume is highly conserved in the fitting procedure, which emphasizes agreement over the five path integrals. Six independent beam paths are sufficient to determine one bivariate Gaussian that has six independent unknown parameters. This can be reduced to four setting the correlation parameter \tilde{n}_{12} equal to zero. This assumes that the reconstructed bivariate Gaussian is limited only to changes in the vertical and crosswind directions. In this case the above equation reduces to:

$$G(r, \varphi) = \frac{A}{2\pi s_y s_z} \exp \left\{ -\frac{1}{2} \left[\frac{(r \cdot \cos \varphi - m_y)^2}{s_y^2} + \frac{(r \cdot \sin \varphi - m_z)^2}{s_z^2} \right] \right\}$$

One also can fix the peak location in the vertical direction to the ground level when ground level emissions are known to exist, as in our field experiment. However, in this methodology, there is no requirement to apply a priori information on the source location and configuration.

Once the parameters of the function were found for a specific run, the concentration values are calculated for every square elementary unit in a vertical domain. These values are integrated incorporating wind speed data at each height level to compute the flux. In this stage, the concentration values are converted from parts per million by volume to grams per cubic meter, considering the molecular weight of the target gas and ambient temperature. The flux is calculated in grams per second, using wind speed data in meters per second. The flux leads directly to a determination of the emission rate (Hashmonay et al., 1998; Hashmonay and Yost, 1999A, Hashmonay et al., 2001). Thus, vertical scan leads to a direct measurement-based determination of the upwind source emission rate.

The Concordance Correlation Factor (CCF) is used to represent the level of fit for the reconstruction in the path-integrated domain (predicted vs. observed PIC). The CCF is similar to the Pearson correlation coefficient, but is adjusted to account for shifts in location and scale. Like the Pearson correlation, CCF values are bounded between -1 and 1, yet the CCF can never exceed the absolute value of the Pearson correlation factor. For example, the CCF will be equal to the Pearson correlation when the linear regression line intercepts the ordinate at 0, its slope equals 1. Its absolute value will be lower than the Pearson correlation when the above conditions are not met. For the purposes of this report, the closer the CCF value is to 1, the better the fit for the reconstruction in the path-integrated domain.

Figure 3 shows a schematic of the experimental setup used for vertical scanning. Several retro reflectors are placed in various locations on a vertical plane in-line with the scanning OP FTIR. The location of the vertical plane is selected so that it intersects the mean wind direction close to perpendicular as practical.

Virtual Flux Box

In concert with wind direction and speed data, the virtual flux box is an alternative ORS technique that yields emission fluxes. This technique is not as well developed as the vertical scanning technique. Conceptually, the virtual flux box may be regarded as three vertical planes (two beams per plane) such that

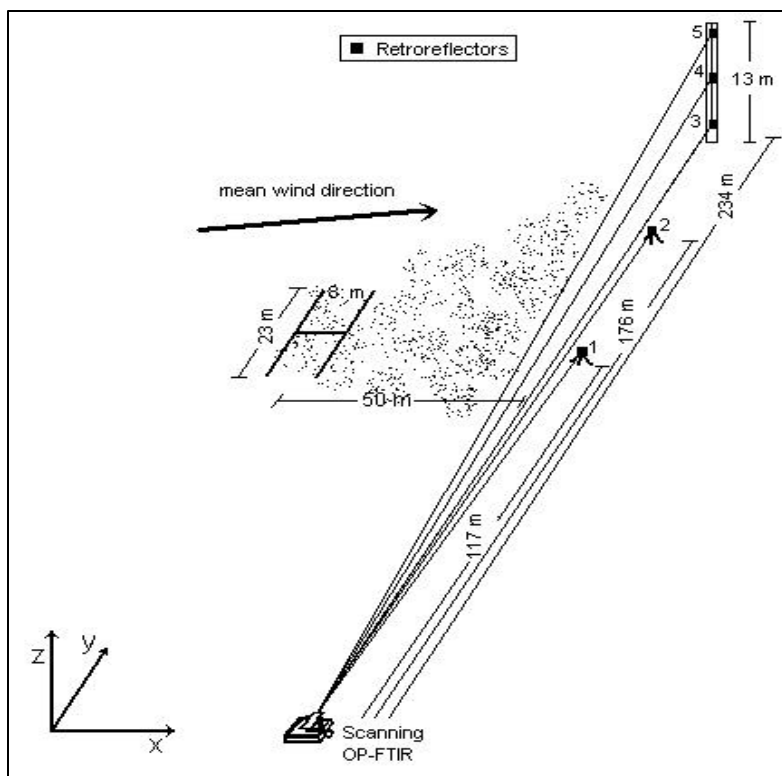


Figure 3. Example Vertical Scanning Configuration

the end points define the corners of the area under test. The virtual flux box was used at the Retrofit Area as backup data in case the vertical scanning configuration did not yield acceptable results (unfavorable wind directions).

Figure 4 illustrates the experimental setup for establishing a virtual flux box. This figure represents the installation of the scanning OP-FTIR in a virtual flux box configuration at an elevated site. The instrument, represented by the circle, is set up in the “southeast” corner. It scans to the retroreflectors (small square symbols) at six of the other seven corners of the virtual cubical box. The red lines represent the optical paths. By analogy to the vertical scanning configuration described previously, three small vertical planes are defined. Application of the SBFM function using a bivariate Gaussian model, will calculate the plume’s size. Emission fluxes are determined from the vertical-plane area-integrated concentration multiplied by the wind speed.

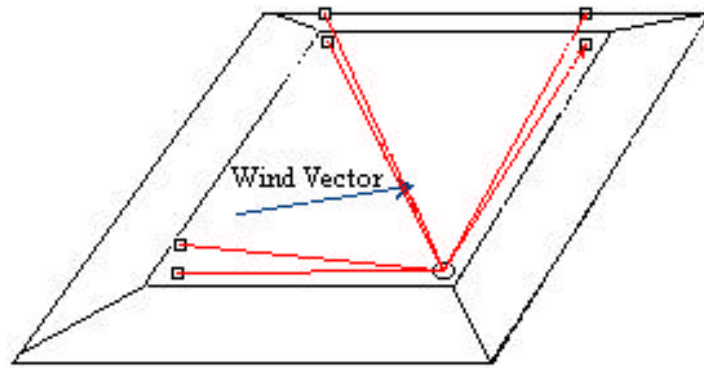


Figure 4. Example of Virtual Flux Box configuration

Data Quality Objectives and Criteria

Data quality objectives (DQOs) were developed using EPA's DQO Process (described in *EPA QA/G-4, Guidance for the Data Quality Objectives Process*) to clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. DQOs define the performance criteria that limit the probabilities of making decision errors by considering the purpose of collecting the data, defining the appropriate type of data needed, and specifying tolerable probabilities of making decision errors.

Quantitative objectives are established for critical measurements using the data quality indicators of accuracy, precision, and completeness. The acceptance criteria for these data quality indicators (DQI) are summarized in Table 1. Accuracy of measurement parameters is determined by comparing a measured value to a known standard. Values must be within the listed tolerance to be considered acceptable. Accuracy can also be measured by calculating the % bias of a measured value to that of a true value.

Precision is evaluated by making replicate measurements of the same parameter and by assessing the variations of the results. Replicate measurements are expected to fall within the tolerances shown in Table 1. Completeness is expressed as a percentage of the number of valid measurements compared to the total number of measurements taken.

Estimated minimum detection limits, by compound, are given in Table 2. It is important to note that the values listed in Table 2 are considered approximate. Minimum detection limits can vary based on atmospheric conditions. Minimum detection levels for each absorbance spectrum are determined by calculating the root mean square (RMS) absorbance noise in the spectral region of the target absorption feature. The minimum detection level is the absorbance signal (of the target compound) that is five times the RMS noise level, using a reference spectrum acquired for a known concentration of the target compound.

Table 1. DQI Goals for Critical Measurements

Measurement Parameter	Sampling Method(s)	Analysis Method	Accuracy	Precision	% Complete
Wind direction	N/A	Magnetic compass with vane	±5° tolerance	±5°	90%
Wind speed	N/A	Heavy duty wind cup set	±0.8 m/s	± 0.8 m/s	90%
Optical path-length	N/A	Theodolite	±1m	± 1 m	100%
Mid-IR absorbance	N/A	FTIR	±10%	± 10%	90%
Elemental Hg	N/A	Lumex	±20%	±20%	90%

Table 2. Detection Limits for Target Compounds

Compound	Sampling/Analytical Method	Est. Detect. Limit for Path Length = 100m, 1 min Ave. (ppmv)	AP-42 Value - Conc in raw landfill gas (ppmv)
Butane	FTIR	0.006	5.03
Carbonyl sulfide	FTIR	0.006	0.49
Chloromethane	FTIR	0.012	1.21
Dichlorodifluoromethane	FTIR	0.004	15.7
Dichlorofluoromethane	FTIR	N/A	2.62
Ethane	FTIR	0.010	889
Ethyl chloride	FTIR	0.004	1.25
Fluorotrichloromethane	FTIR	0.004	0.76
Methane	FTIR	0.024	N/A
Pentane	FTIR	0.008	3.29
Propane	FTIR	0.008	11.1
1,3-Butadiene	FTIR	0.012	N/A
Acetone	FTIR	0.024	7.01
Acrylonitrile	FTIR	0.010	6.33
Benzene	FTIR	0.040	N/A
Bromodichloromethane	FTIR	N/A	3.13
Carbon disulfide	FTIR	0.028	0.58
Carbon tetrachloride	FTIR	0.008	0.004
Chlorobenzene	FTIR	0.040	0.25
Chloroform	FTIR	0.012	0.03
Dimethyl sulfide	FTIR	0.018	7.82
Ethyl mercaptan	FTIR	N/A	2.28
Ethylene dibromide	FTIR	0.006	0.001
Ethylene dichloride	FTIR	0.030	0.41
Hexane	FTIR	0.006	6.57
Methyl chloroform	FTIR	0.006	N/A
Methyl isobutyl ketone	FTIR	0.040	1.87
Methylene chloride	FTIR	0.014	14.3
Propylene dichloride	FTIR	0.014	0.18
t-1,2-Dichloroethene	FTIR	N/A	2.84
Tetrachloroethene	FTIR	0.004	3.73
Toluene	FTIR	0.040	N/A
Trichlorethylene	FTIR	0.004	2.82
Vinyl chloride	FTIR	0.010	7.34
Vinylidene chloride	FTIR	0.014	0.20
Ethanol	FTIR	0.006	27.2
Methyl ethyl ketone	FTIR	0.030	7.09

Compound	Sampling/Analytical Method	Est. Detect. Limit for Path Length = 100m, 1 min Ave. (ppmv)	AP-42 Value - Conc in raw landfill gas (ppmv)
2-Propanol	FTIR	0.006	50.1
1,4-Dichlorobenzene	FTIR	0.012	0.21
Ethyl benzene	FTIR	0.060	4.61
Xylenes	FTIR	0.030	12.1
Hydrogen sulfide	FTIR	6.0	35.5
Methyl mercaptan	FTIR	0.060	2.49
Acetaldehyde	FTIR	0.010	N/A
Formaldehyde	FTIR	0.006	N/A

*N/A indicates that estimated minimum detection levels were not available for a particular compound.

*The AP-42 values represent an average concentration of different pollutants in the raw landfill gas. This is not comparable to the detection limits for the OP-FTIR, which is an average value for a path length of 100 meters across the surface of the area source being evaluated. However, it does provide an indication of the types of pollutants and range of concentrations associated with landfill gas emissions in comparison to the detection limits of the OP-FTIR.

Round 1

Field Activities and Data Collection

Field-testing was conducted as indicated in Table 3 during September of 2002. Data analysis was performed in the months of October 2002 through January 2003.

Magnifications of the areas identified in Figure 1 are provided for each field test location. Within these figures, circles indicate the locations of the bistatic instrument and source. The location of the scanner plus monostatic FTIR is indicated by a circle, and the location of the scissors jack is indicated by the square.

Theodolite measurements of the standard distance, and horizontal and vertical position of each retroreflector (mirror) were taken in each survey area. These measurements are presented in Tables A-1 to A-5 of Appendix A.

As-Built Area

Figure 5 shows the optical configurations used at the As-Built Area. Four surface non-scanning experiments were performed prior to the vertical scan due to limited access time at this site (we would have preferred to conduct a full radial scan). The results were used to determine concentrations of methane and VOCs but there was not enough data to construct a concentration contour map.

The vertical scanning configuration was set up along the southern boundary of the As-Built Area (see Figure 5), since the observed mean wind was from the northeast. Concurrent meteorological data was collected during these tests. Additionally, the bistatic FTIR instrument was operated along the western boundary of the AALB to collect background concentration data, since the prevailing wind direction was initially from the west-northwest.

Table 3. Schedule of ORS Measurements for Round 1

Date	Day of Week	Detail of Work Performed
Sept 5	Thursday	Travel to site
Sept 6	Friday	AM-Arrive at site PM-Begin Survey/Set-up Work
Sept 7	Saturday	Vertical Scanning of Compost Area
Sept 8	Sunday	Radial and Vertical Scanning of As-Built Area
Sept 9	Monday	Vertical Scanning of Biocover Area
Sept 10	Tuesday	Vertical Scanning of Control Area
Sept 11	Wednesday	Radial Scanning of Retrofit Area
Sept 12	Thursday	Vertical Scanning of Retrofit Area
Sept 13	Friday	AM-Virtual Flux Box Scanning of Retrofit Area PM-Travel from site

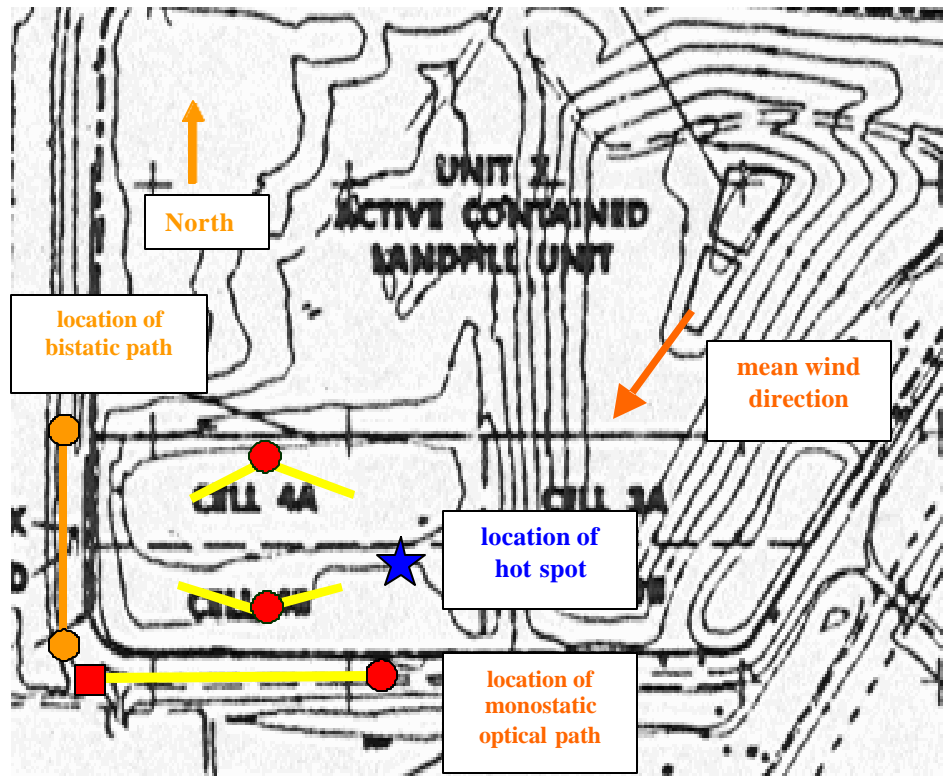


Figure 5. Map of As-Built Area showing Location of Vertical Plane, Surface Scanning, Background Measurements, and possible “Hot Spot”

Retrofit Area

Vertical and horizontal scanning, as well as a virtual flux box configuration was performed at the Retrofit Area test site. Due to the size, dimensions, and collection system configuration of this site, separate experiments of each type were performed on the north and south “halves” of this plateau. Figure 6 shows the vertical configurations used at the Retrofit Area test site. Figure 7 presents the radial scanning configurations used at the Retrofit test site, as well as the location of ten gas extraction pipes observed at the site (denoted by red as well as the location of ten gas extraction pipes observed at the site (denoted by red circles). The locations used for the two vertical plane experiments were defined in permit applications to the FAA. Due to the site’s elevation, proximity to the airport, and the scissor jack height when extended, FAA approval for narrowly defined scissor jack locations was required (North: 38°08’58” N, 85°43’14” W; South: 38°08’51” N, 85°43’14” W). Concurrent meteorological data was collected during these tests. USEPA personnel operated a non-scanning bistatic FTIR along the northern boundary of the Retrofit Area, since the prevailing wind direction was initially from the north. Concurrent meteorological data was collected during these tests. USEPA personnel operated a non-scanning bistatic FTIR along the northern boundary of the Retrofit Area, since the prevailing wind direction was initially from the north.

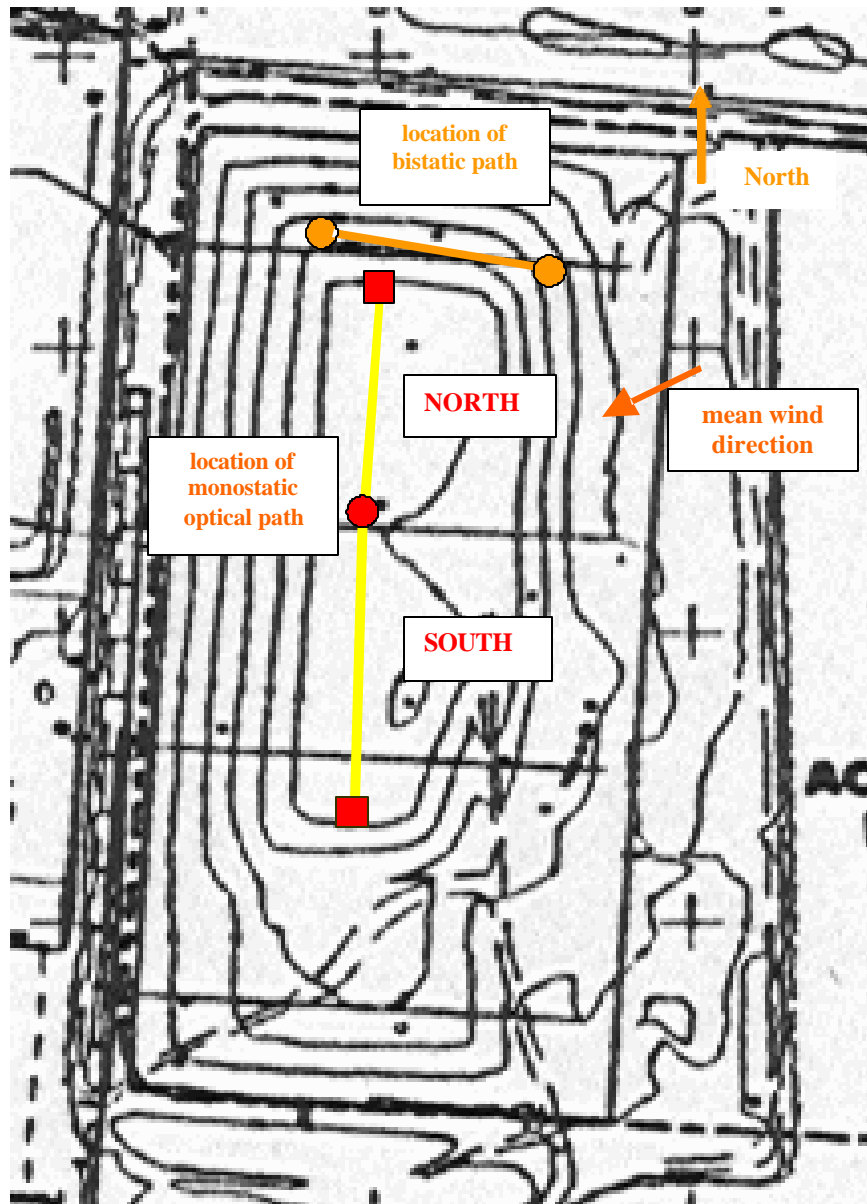


Figure 6. Map of Retrofit Area (North and South) showing Location of Vertical Planes and Background Measurements

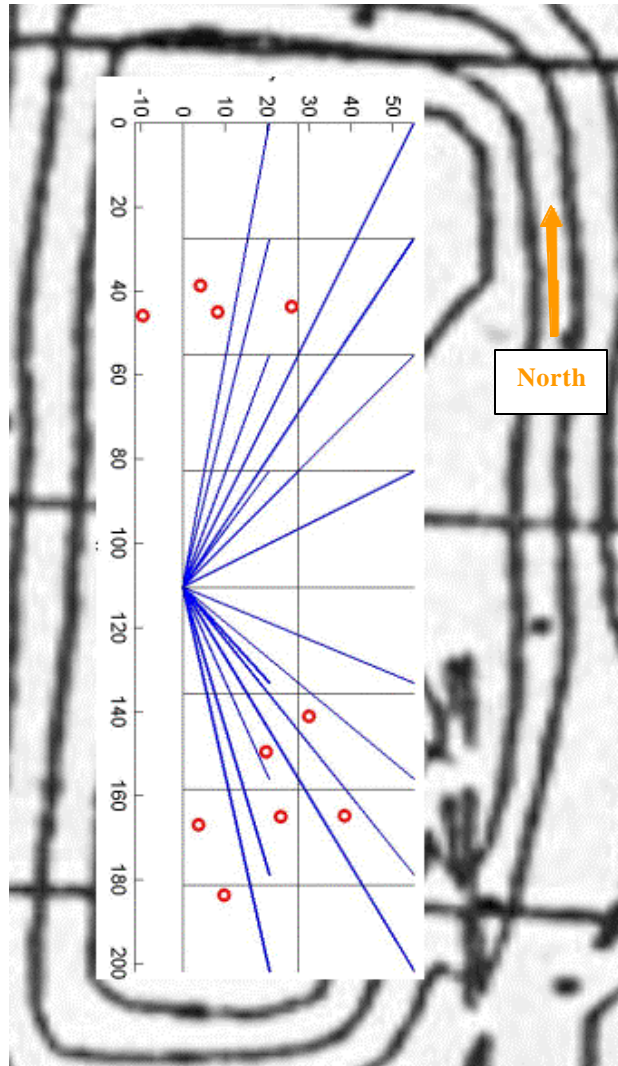


Figure7. Map of Retrofit Area (North and South) showing Location of Mirrors for Radial Scanning and Gas Extraction Pipes

Control Area

Figure 8 shows the vertical configuration used in the Control Area. As mentioned in Section 1.2.7, the Control Area chosen for the study was located north of the As-Built Area. The vertical configuration was set up on the east side of the Control Area, and data was collected during periods that westerly winds were observed at the test site.

Biocover Area

Figure 9 shows the Biocover Area test site. Vertical scan experiments were set up with four mirrors instead of five while the fifth mirror was used as a surface scan along the diagonal of the Biocover Area. The vertical configuration was located directly west of the actual test area (see Figure 9). The favorable wind direction for this configuration would consist of an easterly component. During the period of the survey, westerly, as well as easterly winds were observed at the test site. Actual emission data from the Biocover Area was gathered during periods of easterly winds. The Biocover test site represents a one-acre plot within a conventionally configured landfill.

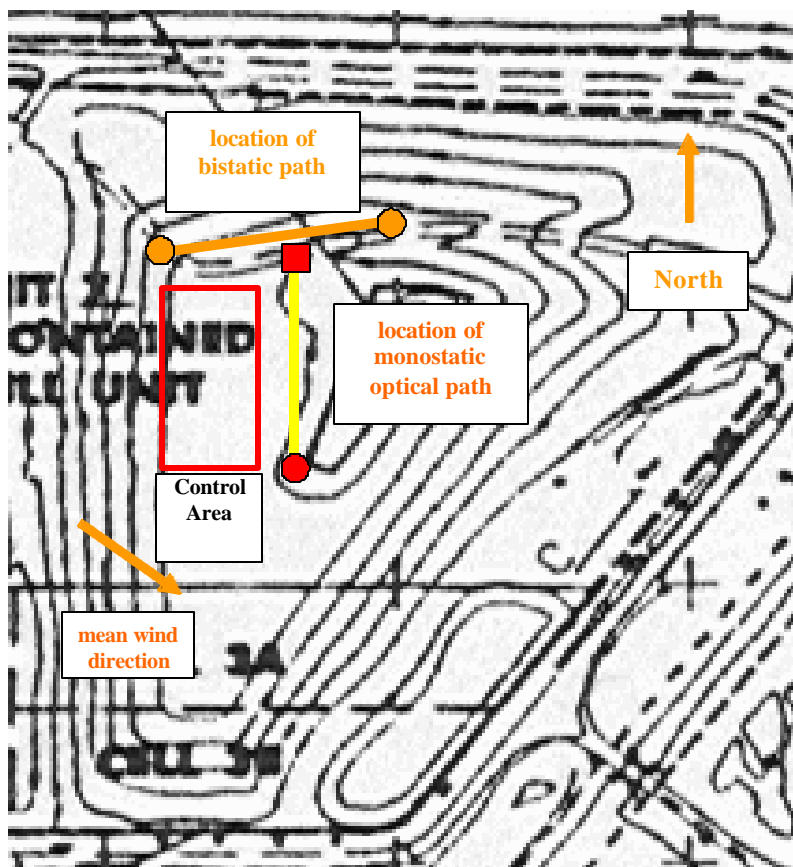


Figure 8. Map of Control Area showing Location of Vertical Plane and Background Measurements

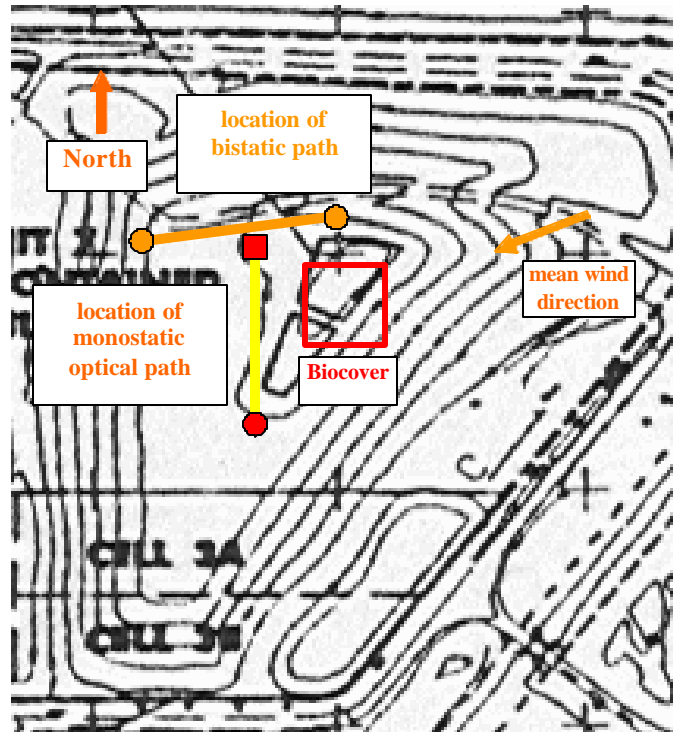


Figure 9. Map of Biocover Area showing Location of Vertical Plane and Background Measurements

Concurrent meteorological data was collected during these tests. A non-scanning bistatic FTIR was operated in an upwind location concurrent with these tests.

Compost Area

Figure 10 shows the Compost Area and the optical configurations used during testing. The large blue circles denote the locations of the compost piles surveyed. Two vertical scanning configurations were setup directly adjacent to two compost piles. It is important to note that physical barriers such as a fence line and the actual location of the compost piles configurations were setup directly adjacent to two compost piles. Physical barriers such as the fence line and the location of the compost piles limited the vertical configuration used for the survey. The winds during the time of the survey fluctuated, but were predominately oriented to the west-northwest. Since the vertical scanning configuration for pile 1 was oriented to the west of the pile, this scanning configuration was considered an upwind measurement.

The scanning configuration used to survey pile 2 was located east of the compost pile, so this was considered a downwind measurement. Concurrent meteorological data was collected during these tests. Background concentration data were collected along the eastern boundary of the Compost Area using the bistatic FTIR instrument.

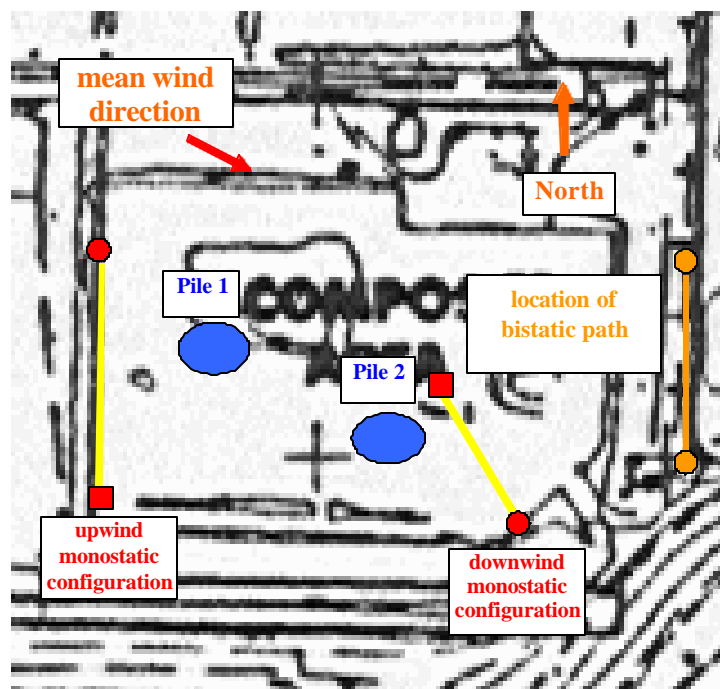


Figure 10. Map of Compost Area showing Locations of Vertical Planes and Location of Background Measurements

Data Analysis and Results

FTIR data were collected as interferograms. All data were archived to CD-ROMs. After archiving, interferograms were transferred to USEPA personnel who performed the transformations to absorbance spectra and then calculated concentrations using a combination of AutoQuant® (Midac) and Non-Lin® (Spectrosoft) quantification software. This analysis was done after completion of the field campaign. Concentration data were matched with the appropriate mirror locations, wind speed, and wind direction. MatLab® (Math-works) software was then used to process the data into horizontal plane concentration maps or vertical plane plume visualizations, as appropriate.

The fluxes are determined as the sum across the matrix of the point-wise multiplication of the concentrations times the wind speed. Emission fluxes for VOCs were calculated by proportioning to the methane flux.

Meteorological data including wind direction and wind speed were continuously collected during the sampling/measurement campaign with a Climatronics model 101990-G1 instrument. The Climatronics instrument is automated. It collects real-time data from its sensors and records time-stamped data as one-minute averages to a data logger. Wind direction and speed-sensing heads were used to collect data at 2 heights, nominally at 2 and 10 meters (the 10 meter sensor was placed on top of the scissors jack). The sensing heads for wind direction incorporate an auto-northing function (automatically adjusts to magnetic north) that eliminates the errors associated with subjective field alignment to a compass heading. The sensing heads incorporate standard cup-type wind speed sensors. Post-collection, the two sets of data were fit linearly to estimate wind velocity as a function of height.

Statistical analysis was performed on several of the data sets to assess data quality and consistency. Average fluxes reported are calculated in the following manner: (a measurement loop mentioned hereafter is a measurement cycle by scanning one time through all the mirrors in

the configuration.): Path-integrated concentration values from measurements made on each beam path (looking at the corresponding mirror) are averaged for four consecutive loops, which satisfy a specified condition for acceptable wind direction. The wind measurements are made at 2m and 10m above ground, and interpolated to six equidistant levels from 2m to 12m. The acceptable wind direction criterion is that the wind direction at 4m height must be within 70 degrees angle from the normal to the plane where the OP-FTIR measurements are made. The measurement plane is the plane in which all the mirrors and the OP-FTIR instrument are placed. All measurement loops which do not satisfy the above wind direction criterion are rejected. The wind speed and wind direction are averaged for our consecutive accepted loops similar to the path-integrated concentrations. A radial plume-mapping algorithm was used to compute the mass-equivalent plume image, and the flux in grams per second across the plane of the measurement. Ideally, one would like to have four loops (that are averaged) measured consecutively, which would be the case with consistent wind conditions. However, with unstable wind conditions and/or with wind directions close to 70 degrees from normal, some loops may be rejected in order to maintain data quality. For example, only 7 out of 16 loops shown in Table B-1 satisfy the wind criterion for the As-Built area, which is reported in Section 3.1. For measurements with more than four loops satisfying the wind criterion, a moving average is made with a grouping of four, and the flux across the measurement plane is calculated. In order to assess the accuracy of reconstruction for each moving average group, the Concordance Correlation Coefficient (CCF) has been computed for each reconstruction. The surface plume concentrations are calculated by calculating a path-integrated average for each pixel. Then, contour lines representing concentrations are drawn by interpolating between the nine average pixel values

As-Built Area

Table 4 presents the methane emission flux from the vertical scanning survey of the As-Built Area. A map of this site and the optical configurations are provided in Figure 5. The first column of this table refers to a running average calculation from the several loops of data collected. The second column shows the calculated CCF. The third, fourth, and fifth columns show the calculated methane flux (in grams per second), and the average wind speed and wind direction during the time the measurements were taken, respectively. The methane concentrations used to create this table can be found in Table B-1 of Appendix B.

Table 4. Moving average of calculated methane flux, CCF, wind speed, and wind direction* for the As-Built Area

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir (deg)
1 to 4	0.980	165	1.91	51
2 to 5	0.977	180	2.38	33
3 to 6	0.962	168	2.52	36
4 to 7	0.958	118	2.15	43
Average	0.969	160		
Std. Dev. of Mean	0.0108	27.3		

*wind direction shown is the angle from a vector normal to the plane of the configuration

Figure 11 presents a map of the reconstructed methane plume from the As-Built vertical scanning survey. Contour lines give methane concentrations in ppm. The average calculated methane flux from the As-Built Area was 160 g/s.

In addition to measuring methane concentrations and methane flux, additional analysis was done to measure emissions of ammonia and VOCs from the As-Built Area. VOC concentrations and fluxes measured at the site were generally either too low to be detected, or were detected in only trace amounts. Consistent with the QAPP, emission concentrations and fluxes for these trace VOCs were calculated by proportioning to the methane concentration and flux.

It is known that methane comprises approximately 50% of landfill gas. Proportioning an estimated methane concentration of 500,000 ppmv to the highest methane concentration found at the site, and ratioing this to the AP-42 value for each target VOC (found in Table 2), it was found that the expected VOC concentrations were often below the estimated minimum detection limit for the target VOC. As mentioned in Section 2.5, this was anticipated prior to performance of the experiments.

Tables 5 and 6 present concentrations and calculated fluxes (in g/s) of VOCs and Ammonia measured during runs 1 and 2, respectively, of the AALB vertical scanning survey. The VOC fluxes were calculated by ratioing the measured methane concentrations with the measured VOC concentrations. For example, in Table 5, the average calculated methane flux value is 118 g/s. The average methane concentration is 109 ppmv. The average calculated ammonia flux is found by first multiplying the ratio of methane to ammonia concentration ($109\text{ppmv} / 0.0049\text{ppmv}$) by the ratio of the molecular weight of methane to ammonia ($16\text{g}/17\text{g}$). This value (20,936.4) is then proportioned to the average calculated methane flux to yield the value of the average calculated ammonia flux (0.0056g/s).

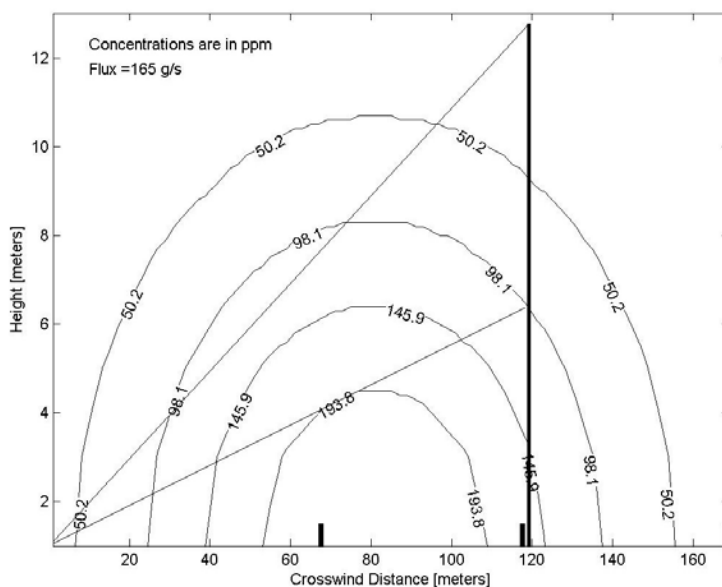


Figure 11. Reconstructed average methane plume from the moving average of loops 1 to 4 of the As-Built Vertical Scanning Survey

Table 5. Average Concentration and Calculated Flux of VOCs, Ammonia, and Methane for As-Built Vertical Scan-Run 1

Compound	Minimum Detection Level (ppmv)	Average Conc. (ppmv)	Flux (g/s)
MTBE*	0.0099	0.0602	0.33
Ammonia	0.0024	0.0049	0.0056
Straight-Chain Hydrocarbons	0.49	1.6	9.2
Bent-Chain Hydrocarbons	0.084	0.47	2.3
Methane		109	118

*MTBE= Methyl tert-butyl ether

Table 6. Average Concentration and Calculated Flux of VOCs for As-Built Vertical Scan-Run 2

NMOC	Minimum Detection Level (ppmv)	Avg. Concentration (ppmv)	Flux (g/s)
MTBE*	0.0098	0.018	0.102
Straight-Chain Hydrocarbons	0.48	0.85	5.1
Bent-Chain Hydrocarbons	0.27	0.95	4.8
Methane		147	165

As was reported above, the average calculated methane flux from the As-Built Area was 160 grams per second. However, this value may be a low estimate of the total methane flux from the As-Built Area. The observed wind direction during the vertical scanning survey was variable. Environments having variable wind directions are classified as unstable. Other studies have found that calculated fluxes could underestimate actual fluxes by as much as 35% in unstable environments [Hashmonay *et al.*, 2001]. Additionally, the axis of the vertical scanning configuration was oriented along the southern boundary of the As-Built Area (see Figure 5). However, due to limitations in the instrumentation, it was not possible for the vertical scanning configuration to include the entire southern boundary of the survey area. The optical range of the OP-FTIR instrument used in this study was approximately 200 meters, which is less than the total distance of the southern boundary of the As-Built Area. Because of this, it is possible that the entire methane plume from the As-Built was not captured by the vertical configuration. Consequently, the calculated methane flux from the As-Built Area may be underestimating the actual flux, but the major identified “hot spot” was fully quantified.

Due to time constraints and instrument limitations discussed in Section 2.1, a complete radial scan of the As-Built Area was not performed to identify the exact location of “hot spots” which may have contributed to the calculated methane flux. However, a non-scanning surface survey was performed in the As-Built using 4 beams. This survey was done over the western and central areas of the As-Built Area (see Figure 5). Concentrations of various compounds (including

methane) were calculated from the four surface non-scanning experiments. The measured concentrations are presented in Tables B-2 to B-5 in Appendix B. Analysis of the wind data revealed that the prevailing wind direction during the vertical scanning survey was from the northeast. With this knowledge of the wind data, (and due to the fact that much lower methane concentrations were found during the surface survey of the western and central areas of the As-Built Area, along with data from the vertical scanning survey which gives plume shape and location with respect to relevant wind direction), we can conclude, based on the method described by *Hashmonay and Yost* [1999A], that any “hot spots” contributing to the methane fluxes calculated were probably located in the eastern portion of the As-Built Area (consisting of cells 4A and 4B). A blue star in Figure 5 of Appendix A denotes the location of this “hot spot”.

3.2.2 Retrofit Area

As mentioned earlier, radial and vertical scanning were performed in the Retrofit area. The radial scanning was performed to identify methane “hot spots”. Figure 12 presents a contour map of reconstructed methane concentrations (in ppm) from this area, and Table B-6 of Appendix B shows actual methane concentrations measured during radial scanning. The figure shows the presence of two distinct “hot spots”, or areas where methane concentrations exceed 79 ppmv. The red circles show the locations of ten gas extraction pipes observed in the Retrofit Area. Tables 7 and 8 present methane emission flux determinations for the northern and southern halves of the Retrofit Area, respectively. The optical configurations for this site are provided in Figure 6. In Table B-7, the measured methane concentrations are provided from the vertical scanning monitoring. The first column of these tables refers to a running average calculation from the several “loops” of data collected. The second column shows the calculated CCF. The third, fourth, and fifth columns show the calculated methane flux (in grams per second), and the average wind speed and wind direction during the time the measurements were taken, respectively.

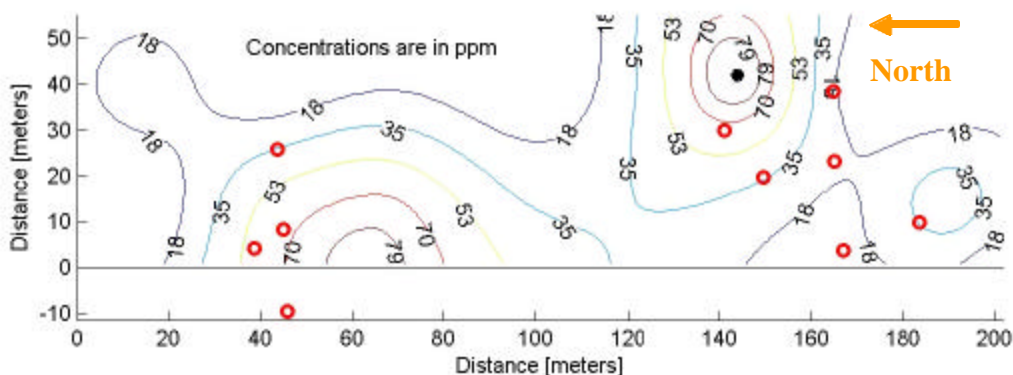


Figure 12. Reconstructed Methane Concentrations (in ppm) for the Retrofit North and South Areas

Table 7. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Retrofit North Area

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	*Wind Dir. (deg)
1 to 4	0.980	19	3.14	355
2 to 5	0.987	18	3.29	356
Average	0.983	19.0		
Std. Dev. of Mean	0.0049	0.707		

*wind direction shown is the angle from a vector normal to the plane of the configuration

Figures 13 and 14 present the reconstructed methane plume from Retrofit North and South vertical scanning survey, respectively. Contour lines give methane concentrations in ppm. The average calculated methane flux for the northern half of the Retrofit Area was 19 grams per second, and the average calculated methane flux for the southern half was 20 grams per second. Two virtual flux box configurations were conducted in the Retrofit Area. The results from this showed consistent emissions results as was found using the vertical scanning measurements. As mentioned earlier, Figure 12 shows that two distinct methane “hot spots” were found in the Retrofit Area. The peak methane concentrations found in each “hot spot” were similar (greater than 79 ppmv). One “hot spot” was located in the Retrofit North area, and one in the Retrofit South area. The proximity of these “hot spots” to the location of the gas extraction pipes (indicated by red circles), and analysis of wind data at the time of the measurements, suggests the pipes may be a significant source of methane emissions.

Closer inspection of the average reconstructed methane plumes from Retrofit North and South vertical scanning surveys (Figures 13 and 14, respectively) show that the average calculated methane fluxes for each area are very similar. This is not surprising, since the methane concentrations found in the “hot spots” for each area (which would be the major contributor to methane flux values) are similar in magnitude. Additionally, the spatial distribution of the plumes in the horizontal direction is consistent with the location of the “hot spots”. The center of the Retrofit North “hot spot” is located about 45 meters north of the position of the scanner. Figure 13 shows that the center of the methane plume found in the Retrofit North area is located about 40 meters from the scanner position. The center of the Retrofit South “hot spot” is located about 30 meters south of the position of the scanner. Figure 14 shows that the center of the methane plume found in the Retrofit South area is located about 35 meters from the scanner position. It appears that there was very good agreement between the location of “hot spots” found during the radial surface scanning surveys, and the plume reconstruction done from the vertical scanning surveys.

Observed wind directions during the Retrofit vertical scanning surveys were stable. This would be indicative of a stable atmosphere. *Hashmonay et al.* [2001] found that fluxes calculated during stable environments may underestimate the actual flux by around 10%.

Table 8. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction* for the Retrofit South Area

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir (deg)
1 to 4	0.976	13	3.30	11
2 to 5	0.937	20	3.96	3
3 to 6	0.924	24	4.06	360
4 to 7	0.939	22	4.12	328
5 to 8	0.931	20	3.94	348
6 to 9	0.941	25	3.88	1
7 to 10	0.968	22	3.75	17
8 to 11	0.954	22	3.52	17
9 to 12	0.986	21	3.57	345
10 to 13	0.992	17	3.71	338
11 to 14	0.981	15	3.41	329
12 to 15	0.991	19	3.57	344
13 to 16	0.989	19	3.70	15
Average	0.962	20		
Std. Dev. of Mean	0.0253	3.40		

*wind direction shown is the angle from a vector normal to the plane of the configuration

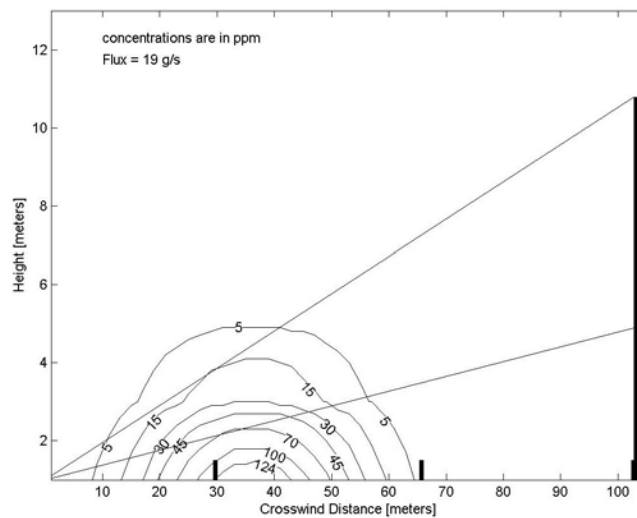


Figure 13. Reconstructed average methane plume from the moving average of loops 1 to 4 of the Retrofit North Vertical Scanning Survey

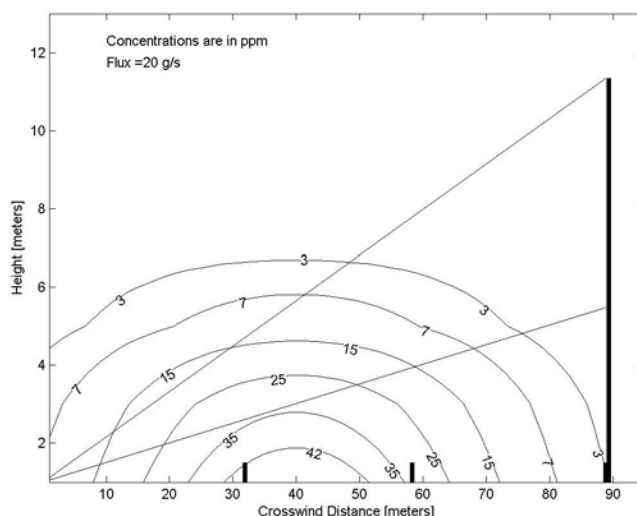


Figure 14. Reconstructed average methane plume from the moving average of loops 5 to 8 of the Retrofit South Vertical Scanning Survey

3.2.3 Control Area

Methane fluxes were calculated in the Control Area for instances when westerly winds were observed. Table 9 presents calculated Control methane fluxes. The first column of these tables refers to a running average calculation from the several “loops” of data collected. The second column shows the calculated CCF. The third, fourth, and fifth columns show the calculated methane flux (in grams per second), and the average wind speed and wind direction during the time the measurements were taken, respectively. The methane concentrations used to create these tables can be found in Table B-8 of Appendix B.

Table 9. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction* for the Background Vertical Scan of the Control Area

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir (deg)
1 to 4	0.973	6.0	0.95	332

*wind direction shown is angle from a vector normal to the plane of the configuration

Figure 15 presents the reconstructed methane plume from the vertical scanning survey of the Control Area. Contour lines give methane concentrations in ppm. The average calculated methane flux was 6 grams per second for the upwind survey.

In addition to measuring methane concentrations and methane flux, analysis was done to measure emissions of ammonia and VOCs from the Control Area. Concentrations of various compounds were calculated from the surface scan (mirror 1), and vertical scan (mirrors 2, 3, 4, and 5) experiments. Tables 10 and 11 present concentrations and calculated fluxes (in g/s) of VOCs and ammonia measured during runs 1 and 2,

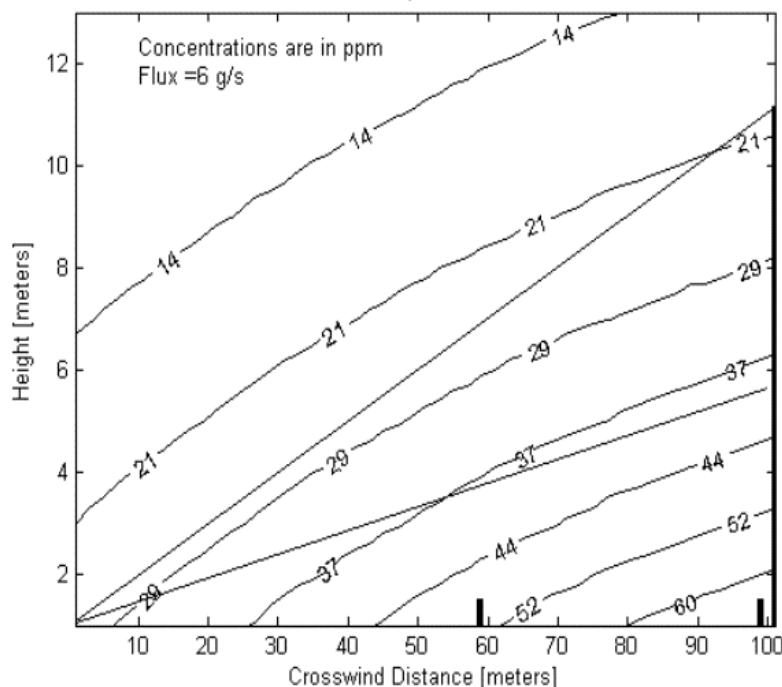


Figure 15: Reconstructed average methane plume from the Control Area Vertical Scanning Survey

respectively, of the Control vertical scanning survey. The fluxes were calculated by ratioing the measured methane concentrations with the measured VOC concentrations.

3.2.4 Biocover Area

Methane fluxes were calculated at the Biocover Area for instances where the vertical configuration was downwind of the actual survey area. Table 12 presents calculated methane fluxes measured at the site. The first column of these tables refers to a running average calculation from the several “loops” of data collected. The second column shows the calculated CCF. The third, fourth, and fifth columns show the calculated methane flux (in grams per second), and the average wind speed and wind direction during the time the measurements were taken, respectively. The methane concentrations used to create these tables can be found in Table B-8 of Appendix B.

Figure 16 presents the reconstructed methane plume from the vertical scanning survey of the Biocover Area. Contour lines give methane concentrations in ppm. The average calculated methane flux for the Biocover Area was 24 grams per second. No other compounds were detected in the Biocover Area

In order to analyze the results of the flux measurements, a comparison of methane flux calculations and wind data was made. Figure 17 presents a time series of methane flux and wind direction, for instances when the vertical configuration was located downwind of the survey area (the data used to create this graph can be found in Table B-8 of Appendix B). There appears to be a relationship between calculated methane flux and observed wind direction. The highest methane concentrations occur shortly after the observed wind direction has a northeasterly component (indicated as a wind direction of -30° to -40° in the figure). This

suggests that methane is being transported through the vertical configuration, from a “hot spot” located somewhere to the northeast of the Biocover Area.

Observed wind directions during the Biocover Area vertical scanning survey were highly variable. This is indicative of an unstable environment. This suggests that the calculated methane flux values could be underestimating the actual methane flux values in this area [Hashmonay *et al.*, 2001].

Table 10. Average Concentration and Calculated Flux of VOCs, Ammonia, and Methane for Control Area Vertical Scan-Run 1

Compound	Minimum Detection Level (ppmv)	Average Concentration (ppmv)	Flux (g/s)
TFM*	0.0018	0.0051	0.0036
CFM*	0.0098	0.034	0.015
Ethanol	0.0107	0.104	0.025
MTBE*	0.0108	0.046	0.019
Ammonia	0.0036	0.0202	0.0018
Methane		66.5	6

*TFM= Trichlorofluoromethane

*CFM= Chlorodifluoromethane

*MTBE= methyl tert-butyl ether

Table 11. Average Concentration and Calculated Flux of NMOCs for Control Area Vertical Scan-Run 2

Compound	Minimum Detection Level (ppmv)	Average NMOC Conc (ppmv)	NMOC Flux (g/s)
Ethylene	0.0041	0.0083	0.0014
CFM*	0.0097	0.031	0.016
Ethanol	0.0099	0.065	0.018
MTBE*	0.0101	0.037	0.019
Ammonia	0.0026	0.019	0.0019
Methane		57	5

*CFM= Chlorodifluoromethane

*MTBE= methyl tert-butyl ether

Table 12. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction* for the downwind vertical scan of the Biocover Area

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir (deg)
1 to 4	0.981	27	1.13	332
2 to 5	0.994	22	1.06	341
3 to 6	1.000	18	0.87	349
4 to 7	1.000	17	0.67	354
5 to 8	1.000	16	0.83	327
6 to 9	1.000	15	0.99	320
7 to 10	0.996	18	1.19	355
8 to 11	0.990	19	1.37	348
9 to 12	0.994	18	1.45	347
10 to 13	0.983	15	1.35	19
11 to 14	0.994	18	1.28	348
12 to 15	0.985	16	1.07	356
13 to 16	0.980	16	0.89	2
14 to 17	0.976	17	0.83	333
15 to 18	0.966	22	1.10	324
16 to 19	0.973	25	1.62	314
17 to 20	0.974	36	2.70	316
18 to 21	0.979	35	3.30	346
19 to 22	0.983	23	3.58	356
20 to 23	0.984	24	3.89	3
21 to 24	0.975	28	3.03	355
22 to 25	0.982	12	3.31	317
23 to 26	0.996	25	3.62	315
24 to 27	0.999	27	3.68	319
25 to 28	1.000	25	4.39	321
26 to 29	0.997	32	4.67	329
27 to 30	0.931	45	4.97	334
28 to 31	0.936	37	4.88	339
29 to 32	0.949	34	4.68	337
30 to 33	0.953	33	4.12	338
31 to 34	0.992	28	3.92	6
32 to 35	0.993	28	3.97	4
Average	0.932	24		
Std. Dev. of Mean	.0183	7.96		

*wind direction shown is angle from a vector normal to the plane of the configuration

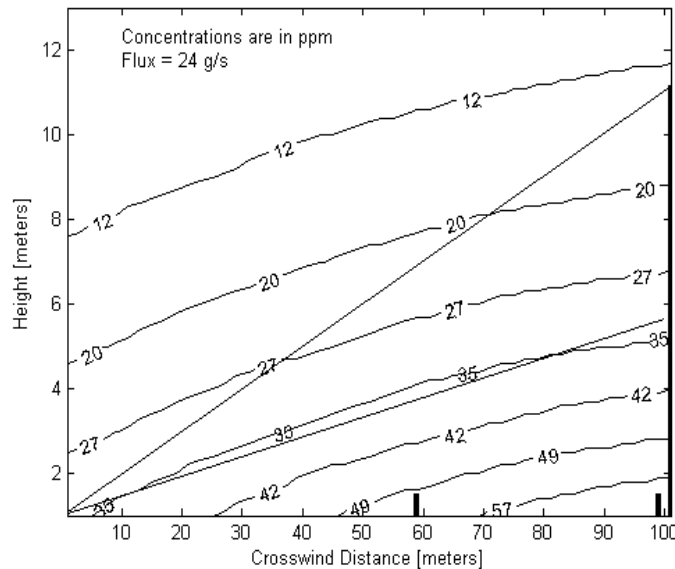


Figure 16. Reconstructed average methane plume from the moving average of loops 20 to 23 of the Biocover Vertical Scanning Survey

3.2.5 Compost Area

The methane concentrations found in this area are presented in the Tables B-10 and B-11 of Appendix B. The results of the Compost Area survey show that the average methane concentrations found were higher in the upwind area than in the downwind area. The survey did not detect any methane plume originating from the compost piles, which was expected. Due to these findings, we conclude that the Compost Area is not a source of methane at the site. Additionally, no other compounds were detected at the Compost Area.

3.2.6 Upwind Measurements

Throughout the period of optical scanning measurements, USEPA personnel set up and operated a bistatic OP-FTIR separate instrument in an upwind location, using a classical non-scanning configuration. Data collected by this instrument are representative of background concentrations from ambient, or upwind, sources. Background data were collected in each of the survey areas (refer to Figures 5, 6, 7, 8, and 9 for the location of the bistatic OP-FTIR configuration, which is denoted by the orange lines). Due to instrumentation problems, background OP-FTIR data is only available from the As-Built and Compost Areas. However, analysis of the surface scanning data from the Retrofit Area provides some information on background methane concentrations in this portion of the landfill.

The background survey from the As-Built Area found an average background methane concentration of 8.6 ppmv. Figure 5 shows that the bistatic OP-FTIR configuration was located along the western boundary of the As-Built Area, and the observed mean wind direction was from the northeast. Due to this, we can determine that the average background methane concentration found was probably indicative of a true background methane measurement for the As-Built Area.

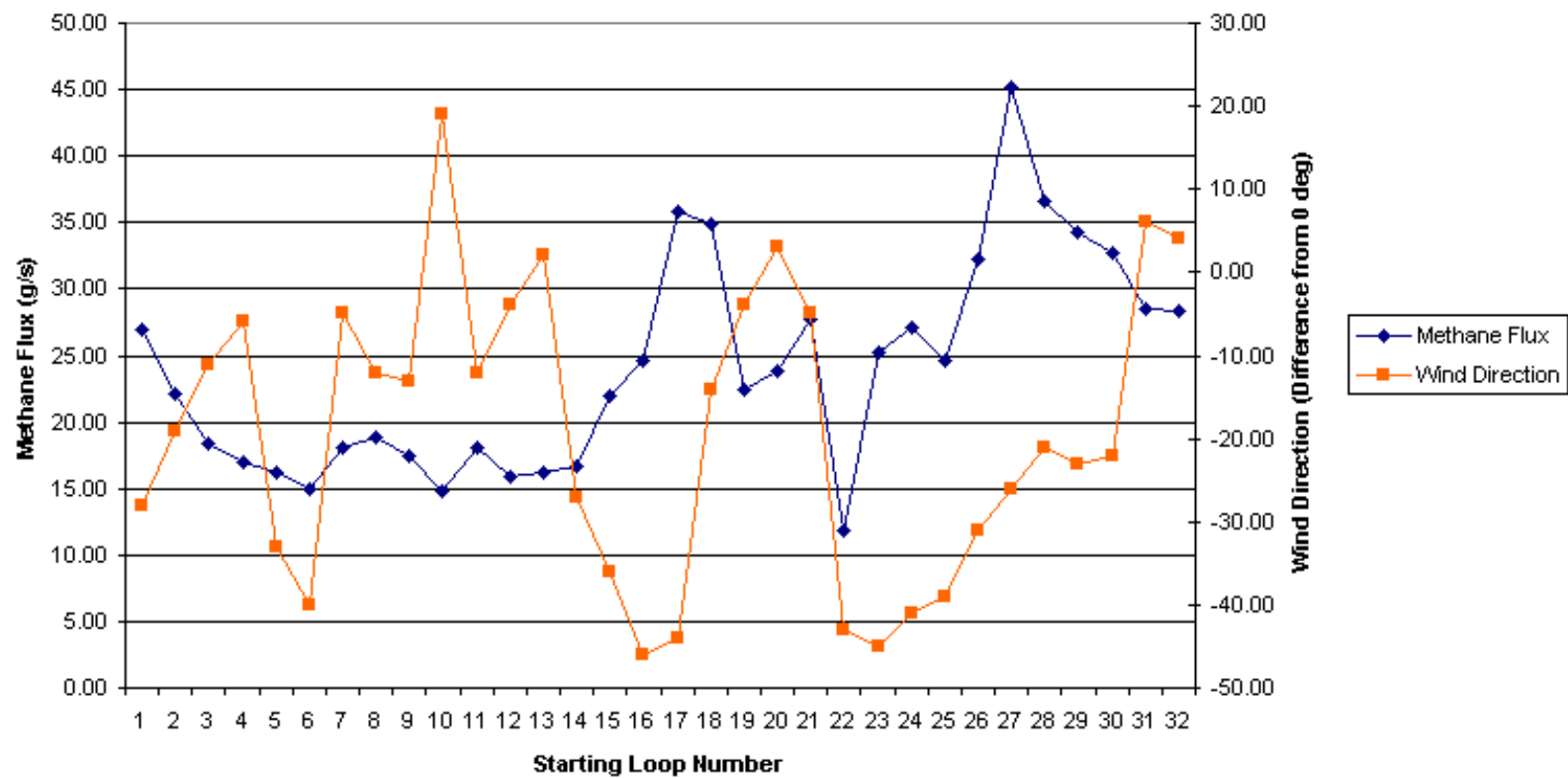


Figure 17: Time Series of Calculated Methane Flux vs. Measured Wind Direction for the Biocover (using moving average of 4 loops)

As mentioned above, the background OP-FTIR data from the Retrofit Area was unavailable due to instrumentation problems. However, in looking at the boundaries of the surface radial scanning results (Figure 12), one can estimate the background concentrations to be about 10 ppmv.

The background survey from the Compost Area found an average background methane concentration of 5.1 ppmv. This background value is very similar to the values detected immediately downwind from the compost piles, reinforcing the conclusion that no methane is emitted from the piles.

3.3 Data Quality Assurance and Control

In preparation for this project, a Category III Quality Assurance Project Plan (QAPP) was prepared and approved prior to the field campaign. In addition, standard operating procedures were in place during the survey, and the study was audited in the field and during post analysis.

3.3.1 Assessment of DQI Goals

The critical measurements associated with this project and the established data quality indicator (DQI) goals in terms of accuracy, precision, and completeness are listed in Table 1 of this document. Assessment of these measurements is discussed in the following subsections.

3.3.2 Meteorological/Theodolite Data

The Climatronics meteorological heads (which are used to collect wind direction, wind speed, ambient temperature, barometric pressure, and relative humidity), and the theodolite have recently been calibrated. The calibration of all instruments used to collect both critical and non-critical measurements should have occurred prior to the current field campaign.

Although calibration of the Climatronics heads did not occur prior to the field study, both Climatronics heads were calibrated in March 2003 by the USEPA/APPCD Metrology Lab (the last calibration of both heads occurred in November 1999). All functions were checked during the March 2003 calibration, and the only adjustment made was approximately a 4 degree change to wind direction for one of the Climatronics heads. As shown in Table 1, accuracy within 5% is an acceptable range, and this variance will have very little bearing on the final flux estimate.

It should also be noted that the wind direction measurement is not as critical to the flux estimates as the wind speed measurement. Additionally, checks for agreement of the wind speed and wind direction measured from the two heads (2m and 10m) were done. While it is true that some variability in the parameters measured at both levels should be expected, this is a good first-step check for assessing the performance of the instruments.

The Climatronics meteorological heads used in the current study were also used as part of a validation study [Hashmonay *et al.*, 2001], and a study done in October, 2002 to measure fugitive emissions at a Region I Landfill in New Hampshire. In both controlled release studies, calculated emission rates were within 65-96% of the actual controlled release rate. The wind measurements taken during these studies provided good flux calculations and therefore were representative of the wind field in the whole vertical plane. Due to these factors, we feel that the accuracy and precision of the Climatronics heads, as stated in the QAPP and by manufacturer's specifications, are sufficient to provide favorable results using this method.

It has been determined that the accuracy of the measured optical path-lengths (which are collected using the theodolite), as stated in the QAPP and by the manufacturer's specifications, are not crucial to our method. However, calibration of the theodolite was done in the field during May 2003. The optical path-length was checked by measuring a standard distance of 50 feet (15.24 meters). The same distance was measured twice using the theodolite, and yielded distances of 15.43 and 15.39 meters. These results fall well within the acceptable accuracy range

stated in Table 1. The horizontal angle was checked by setting up two targets approximately 180° apart, measuring the two horizontal angles between the targets, and summing these values. The sum of the two values should be 360°. These angles were measured twice using the theodolite. The first test yielded a sum of 359°21'18", and the second test yielded a sum of 359°59'55". Both of these values fall well within the acceptable accuracy range stated in Table 1.

3.3.3 OP-FTIR Measurements

As a QC check of the accuracy of the OP-FTIR, we have verified the measurement of the known atmospheric background nitrous oxide concentration of around 320 ppbv from data taken with the monostatic OP-FTIR. It should be noted that 320 ppbv is an average value, as the atmospheric background value exhibits a slight seasonal variation. The data was taken from a sample of the actual data collected during the current field campaign. The average nitrous oxide concentration found was 311 ± 36.24 ppbv. The average value falls within the accuracy goal of 5%.

Additionally, we follow DQI procedures for proper operation as described in EPA Compendium method TO-16, and the OP-FTIR EPA Guidance Document. However, TO-16 is somewhat of an outdated method that does not fully address the issue of non-linearity. Since the completion of the TO-16 document, significant research has been performed by APPCD researchers to improve analysis over a wide range of concentrations [Childers *et al.*, 2001]. Application of the newly developed Non-Lin® software (developed by Spectrosoft) will provide better response of the OP-FTIR technique to higher levels of concentrations [Childers *et al.*, 2002].

Tracer release is the ultimate DQI for confirming the RPM method as a whole system.

Approximately three weeks after completion of the current study, another study was done using the ORS-RPM method at another site. During this study, a tracer release was done using ethylene. The same instrumentation used in the current study was used during this study.

Ethylene was released through a soaker hose configuration located directly west of the vertical scanning survey. The wind direction during the time of the release was almost due west, which allowed the vertical configuration to capture the plume from the tracer release. The soaker hoses were set up in an "H" configuration to simulate an area source. The approximate dimensions of the "H" configuration were 10 meters wide, and 40 meters long (on each side). The weight of the ethylene cylinder was recorded prior to release of the gas, and immediately after the release was completed, using a digital scale. In addition, the precise starting and ending time of the release was recorded in order to calculate the average actual flux of ethylene. This flux value was then compared to the ethylene flux calculated from the vertical scanning survey.

The emission flux through the vertical measurement plane, calculated from the area integration of the concentration profile multiplied by the component of the wind speed normal to the vertical plane was determined as 0.98 g/sec. Since the measurement plane captured the entire plume, the entire flux through the plane is the emission rate of ethylene.

The ethylene tracer gas was released for 75 minutes. During this period, the measured mass of the ethylene cylinder was reduced by 4.59 kg. A loss of 4.59 kg over a 75-minute period indicates an average flow rate of 1.02 g/sec. The measured emission rate agrees with this mass-loss determination to 3.9 percent.

The flux of the ethylene release determined by mass-loss agrees well with the average ethylene flux calculated from the vertical scanning survey. Observed wind directions during the vertical scanning survey were not highly variable. This would be indicative of a stable atmosphere.

Hashmonay *et al.* [2001] found that fluxes calculated during stable environments underestimated

the actual flux by around 12 %. The average ethylene flux calculated during the current experiment underestimated the actual average ethylene flux by 3.9 %.

In addition to verifying data collected with the OP-FTIR instruments a process audit was done by personnel not involved in the data analysis process, to verify that the transfer of data was done accurately. The audit consisted of verifying that concentration data provided by USEPA personnel, as well as wind speed and direction data were input into the reconstruction programs accurately. The results of the audit showed that this process was indeed done accurately.

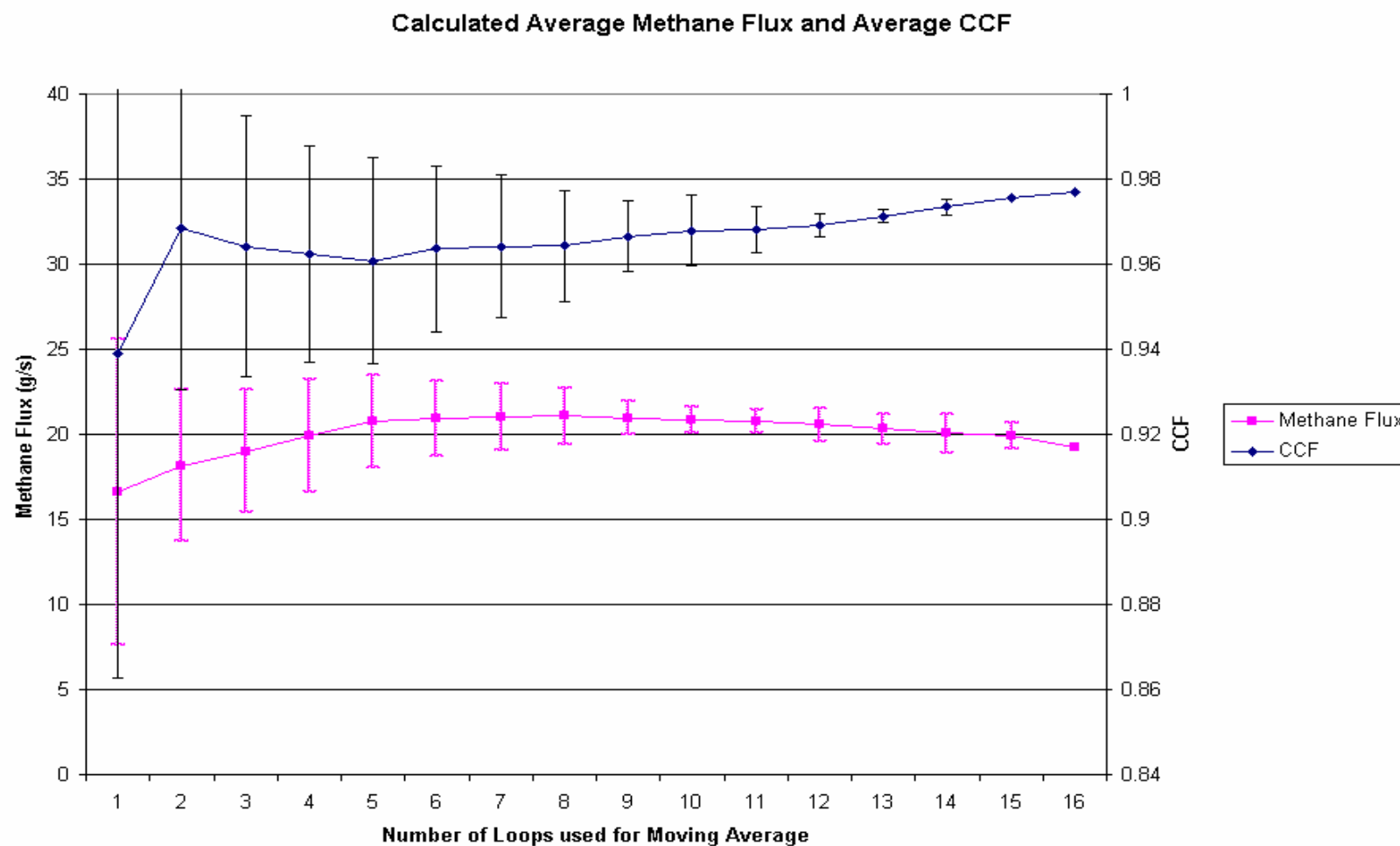


Figure 18. Calculated Average Methane Flux and Average CCF from the Retrofit South Vertical Scanning Survey

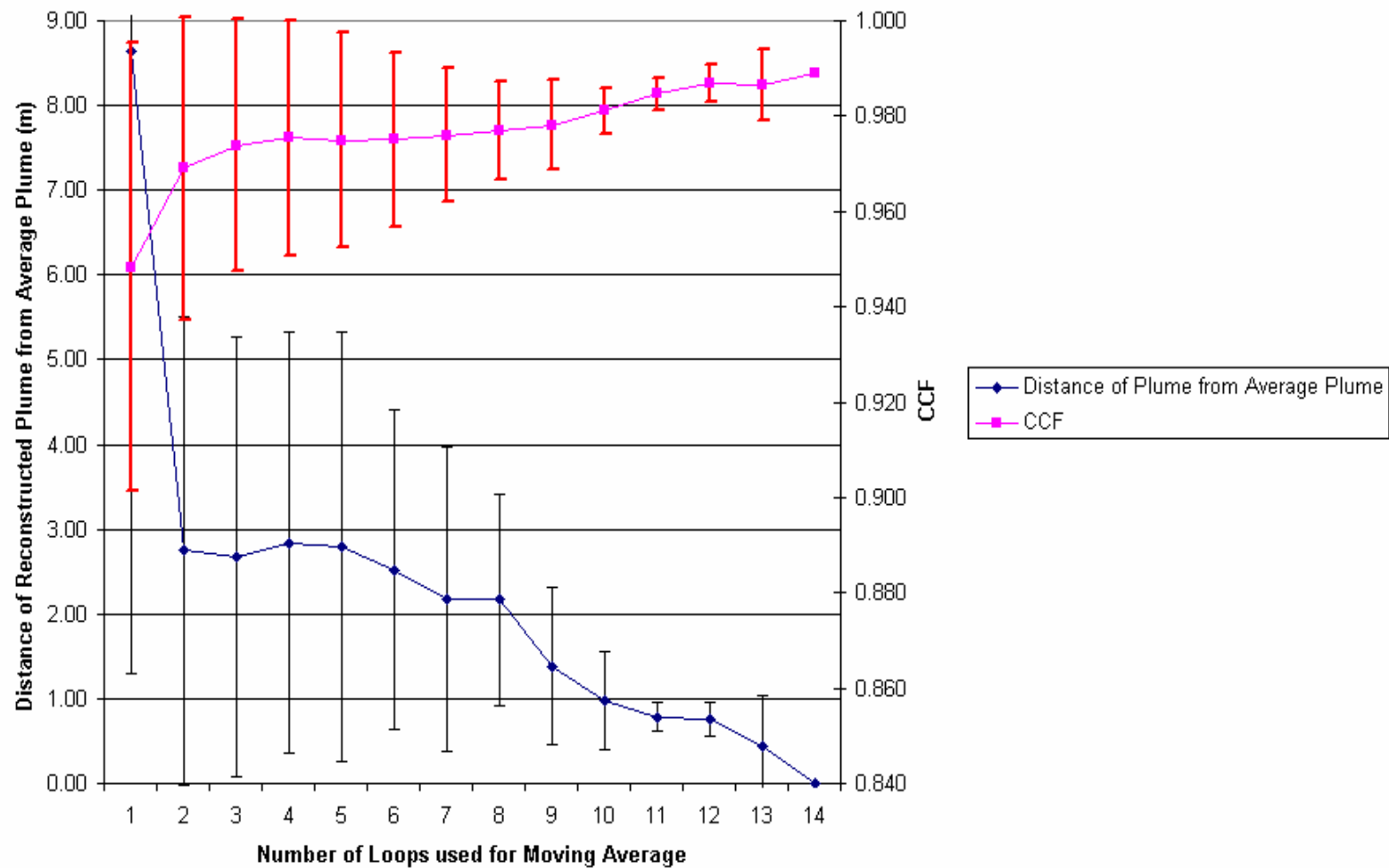


Figure 19. Distance of the Reconstructed Plume from the Average Plume, and Average CCF for the Retrofit North Area Radial Scanning Survey

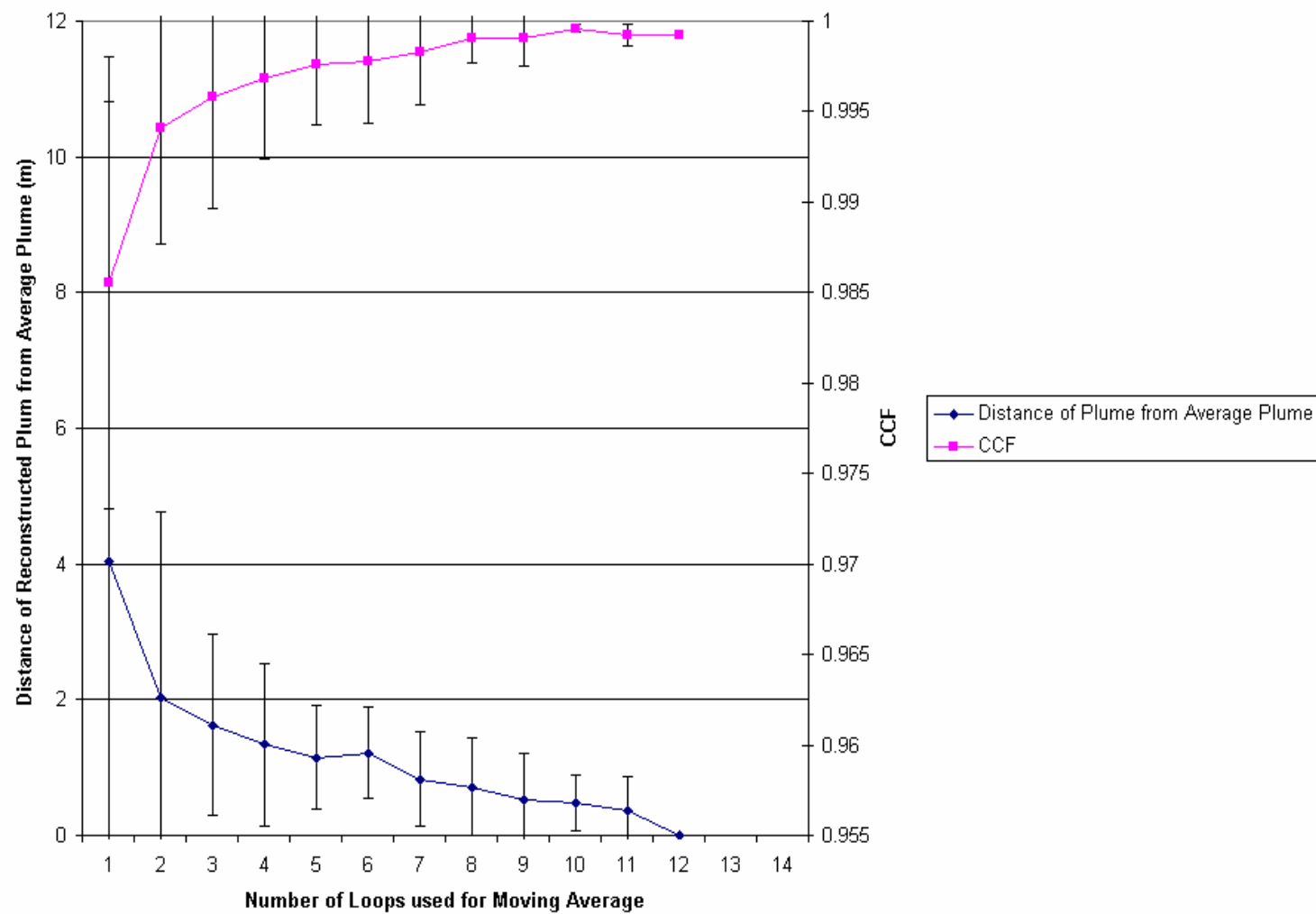


Figure 20. Distance of the Reconstructed Plume from the Average Plume, and Average CCF for the Retrofit South Area Radial Scanning Survey

3.3.4 Problems Encountered and Data Limitations

During the course of the field campaign, the project ran into some instrumentation problems and limitations, which slightly hindered some aspects of the data collection process. These included geographic barriers at the site, limitations in the optical range of the OP-FTIR instrument, and scanner errors that occurred primarily in the Retrofit Area.

The optical range of the OP-FTIR instrument used in this study was approximately 200 meters. The optical range is affected by many factors such as weather conditions, and topography at the site. This limitation primarily affected measurements taken in the As-Built Area. As mentioned in Section 3.1, the vertical scanning survey was oriented along the southern boundary of the survey area. Because of the limitation in the optical range of the OP-FTIR, it was not possible for the configuration to include the entire southern boundary of the As-Built Area. Due to this, it is probable that the calculated methane flux from the As-Built Area may be underestimating the actual flux. More advance OP-FTIR instruments can easily have a range of 500m in similar conditions.

Scanning errors occurred when the actual scanner (used to scan the OP-FTIR between each retroreflector in a configuration) stopped scanning. When this problem occurred, it prevented the completion of the survey, and the scanning program had to be reprogrammed. It is unclear what causes the scanning errors, but these errors occurred most frequently in the Retrofit Area, which may receive electromagnetic energy from air traffic as a result of it being located next to the airport and in the path of in-coming flights.

4 Conclusions

This report provides the first round of testing that is part of a longer-term effort to evaluate the performance of landfill bioreactor operations. The site has two different bioreactor operations (As-Built and Retrofit Areas). OP-FTIR measurements were conducted at the As-Built Area, where liquid additions are introduced at the work face. Sampling for this had to occur over the weekend when hauling operations were not active. The other type of bioreactor being evaluated is the Retrofit Area. This area was split into 2 different sections that were evaluated independently (north and south). In addition to evaluating the two types of bioreactors, the use of vegetative cover to reduce fugitive emissions (referred to as biocover) was evaluated. Emissions from the composting operation were also evaluated. Since this is an aerobic operation, methane emissions were not expected or found. Table 13 presents the average calculated methane fluxes, and the range of flux values, found at each area.

Table 13. Average Calculated Methane Flux (g/s) Found at Each Survey Area

Survey Area	Calculated Methane Flux	Range of Flux Values Calculated
As-Built	160 ± 27.3	118 to 180
Retrofit	39 ± 4.11	31 to 44
Control	6.0	6
Biocover	24 ± 7.96	12 to 45
Compost	N/A	N/A

The As-Built Area was found to have the highest methane fluxes, while the Control and Biocover Areas had the lower methane fluxes. The Compost Area was not found to be significant source of methane which one would expect since it is an aerobic operation.

In addition to vertical scanning, surface scanning was done in the As-Built Area and Retrofit Areas. Two definitive methane “hot spots”, having concentrations over 79 ppmv were found at the Retrofit Area.

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Appendix A

Site Configurations

Table A-1. Standard Distance, and Horizontal and Vertical Coordinates of mirrors used for Vertical and Horizontal Scanning in the As-Built Area

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle* (deg)
Vertical			
1	67.1	270	0
2	116	276	0
3	167	274	0
4	117	275	3
5	118	276	6
As-Built Lower Surface			
1	70.5	291	
2	79.8	60	
As-Built Upper Surface			
1	109	244	
2	110	121	

*Vertical angle shown is the angle from horizontal (positive values indicate elevation from the horizontal, negative values indicate descent from the horizontal).

Table A-2. Standard Distance, and Horizontal and Vertical Coordinates of mirrors used for Vertical Scanning in the Retrofit Area

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle* (deg)
North			
1	29.7	4	0
2	65.7	13	0
3	102	8	0
4	103	7	2
5	104	8	6
South			
1	31.8	158	0
2	58.2	172	0
3	88.7	177	0
4	91.9	176	3
5	93.1	177	7

*Vertical angle shown is the angle from horizontal (positive values indicate elevation from the horizontal, negative values indicate descent from the horizontal).

TableA-3. Standard Distance, and Horizontal Coordinates of mirrors used for Radial Scanning in the Retrofit Area

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
North		
1	55.5	67
2	72.2	47
3	34.3	44
4	92.7	36
5	115	30
6	56.4	25
7	84.3	18
8	108.8	13
South		
1	89.1	181
2	69.7	175
3	52.2	163
4	104	160
5	84.7	154
6	34.1	143
7	67.5	142
8	55.7	125

Table A-4. Standard Distance, and Horizontal and Vertical Coordinates of mirrors used for Vertical Scanning in the Biocover and Control Areas

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle* (deg)
1	109	36	0
2	59.8	2	0
3	99.8	0	0
4	100	359	3
5	101	0	6

*Vertical angle shown is the angle from horizontal (positive values indicate elevation from the horizontal, negative values indicate descent from the horizontal).

Table A- 5. Standard Distance, and Horizontal and Vertical Coordinates of configurations used for Vertical Scanning in the Compost Area

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle* (deg)
Upwind			
1	39.3	183	0
2	103	185	0
3	133	184	0
4	135	182	1
5	136	183	3
Downwind			
1	23.4	325	0
2	49.8	330	0
3	51.9	325	4
4	52.8	328	8

*Vertical angle shown is the angle from horizontal (positive values indicate elevation from the horizontal, negative values indicate descent from the horizontal).

Appendix B

Methane, Ammonia, and VOC Concentrations

Table B-1.Methane Concentrations (in ppm) found during the As-Built Vertical Scanning Survey

Loops	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Wind Speed (m/s)	Wind direction from normal to vertical plane (deg)	Comments
1	23.0	86.1	113	155	136	0.6	52	Loop Used
2	192	196	158	97.8	53.3	1.9	28	Loop Used
3	167	206	162	90.1	60.8	2.5	39	Loop Used
4	154	207	160	103	82.1	1.7	46	Loop Used
5	177	246	183	80.7	33.9	1.8	73	Loop not used-does not meet wind criteria
6	51.4	96.7	154	118	86.0	1.7	75	Loop not used-does not meet wind criteria
7	149	255	176	108	47.3	1.4	75	Loop not used-does not meet wind criteria
8	84.0	140	117	70.4	60.7	2.5	30	Loop Used
9	149	134	84.9	62.8	52.7	2.3	36	Loop Used
10	125	183	142	64.6	42.5	3.0	75	Loop not used-does not meet wind criteria
11	107	140	129	47.1	50.2	2.7	78	Loop not used-does not meet wind criteria
12	73.7	177	167	69.3	40.9	2.2	75	Loop not used-does not meet wind criteria
13	67.5	91.8	49.2	59.1	98.5	1.5	97	Loop not used-does not meet wind criteria
14	178	157	128	70.1	59.2	1.2	69	Loop Used
15	98.2	236	170	53.4	22.9	0.8	85	Loop not used-does not meet wind criteria

Table B-2. Concentrations of Methane and VOCs (in ppmv) Measured on Mirror 1 of the As-Built Lower Surface Scan

As-Built Lower			Conc. (ppmv)	
Mirror 1				
Loop	Methane	Acetylene	Ethanol	Straight-Chain HCs
1	26	0.038		
2	27			
3	21	0.031		
4	24			
5	31			
6	41			
7	32			
8	31			
9	31	0.033		
10	35			0.055
11	31			0.064
12	26	0.018		
13	21			
14	23		0.035	
15	29			
16	22		0.038	0.057
17	32			
18	23			
19	23			
20	23			
	Avg=28			

Table B-3. Concentrations of Methane, VOCs, and Ammonia (in ppmv) Measured on Mirror 2 of the As-Built Lower Surface Scan

As-Built Lower		Concentrations	(ppmv)		
Mirror 2				Straight- Chain	Bent-Chain
Loop	Methane	Ethanol	Ammonia	Hydrocarbons	Hydrocarbons
1	13		0.0095		
2	15		0.0086		
3	13				
4	22		0.0060		
5	22		0.0063		
6	17				
7	21		0.015		
8	21		0.012	0.022	
9	13				
10	23		0.0066		
11	19				
12	17		0.0058	0.017	
13	14	0.0075			0.014
14	11				
15	11				
16	18				
17	19	0.0074			
18	11		0.0055		
19	21		0.0063		
20	11	0.0095			
	Avg=17				

Table B-4. Concentrations of Methane and VOCs (in ppmv) Measured on Mirror 1 of the As-Built Upper Surface Scan

As-Built Upper			Concentration (ppmv*m)		
Mirror 1					
Loop	Methane	Ethylene	Acetylene	Ethanol	MTBE*
1	24		0.0098		
2	18	0.0082	0.028		
3	27	0.0082	0.024		
4	25				
5	32		0.0067		
6	19				
7	29				
8	33				
9	37				
10	28			0.0055	
11	29				
12	23				
13	29				
14	19			0.012	
15	26			0.015	
16	25			0.015	
17	31			0.021	
18	27			0.020	0.0047
19	25			0.022	
20	28	0.0082	0.019	0.025	
	Avg=27				

* MTBE = Methyl tert-butyl ether

Table B-5. Concentrations of Methane, VOCs, and Ammonia (in ppmv) Measured on Mirror 2 of the As-Built Upper Surface Scan

As-Built Upper		Concentrations			
Mirror 2					
Loop	Methane	Ethylene	Acetylene	Ethanol	Ammonia
1	26		0.0038		
2	21		0.00077		
3	27	0.0057	0.011		
4	24				
5	28				
6	15		0.0054	0.011	
7	39	0.0087	0.022	0.0078	
8	31		0.0036		
9	24		0.0041		
10	31				
11	16	0.0053	0.017		
12	13				
13	12				0.0038
14	22		0.0049		0.0035
15	35	0.0092	0.020	0.025	
16	24		0.011		
17	22				
18	27	0.0079	0.017		
19	33		0.012		
20	36		0.0072	0.011	0.0023
	Avg=25				

Table B-6. Methane Concentrations (in ppm) found during the Retrofit Radial Scanning Survey

Loops	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
Radial North								
1	52	26	68	21	57	49	63	48
2	36	31	52	36	62	26	30	25
3	41	24	83	28	51	43	41	61
4	52	25	77	28	80	53	49	35
5	47	19	57	29	49	40	29	42
6	48	22	50	29	49	32	23	36
7	15	19	27	25	61	18	34	25
8	46	11	63	37	67	36	33	57
9	43	24	64	41	49	30	19	41
10	10	4	29	25	69	20	31	24
11	45	15	53	27	50	31	51	55
12	22	26	37	34	61	26	56	25
13	12	28	52	25	66	17	46	36
14	40	16	38	34	59	39	26	28
Radial South								
1	67	54	38	32	33	45	53	50
2	40	71	48	26	28	28	53	61
3	36	76	45	52	29	39	32	50
4	52	94	54	35	53	32	45	67
5	36	50	49	46	37	31	44	63
6	36	63	46	34	50	23	32	45
7	31	48	53	34	18	39	37	37
8	42	83	46	37	41	42	38	38
9	25	53	45	32	32	32	40	33
10	15	41	48	29	25	32	28	35
11	18	58	44	29	44	32	37	36
12	22	36	41	23	27	36	30	31

Table B-7. Methane Concentrations (in ppm) found during the Retrofit Vertical Scanning Survey

Loop	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Wind Speed (m/s)	Wind Direction from normal to vertical plane (deg)	Comments
Retrofit North								
1	20.9	87.2	51.3	15.5	12.0	2.7	347	Loop Used
2	48.3	62.0	36.4	11.9	5.1	2.7	6	Loop Used
3	32.7	71.1	35.3	6.7	3.1	3.8	354	Loop Used
4	25.3	65.3	36.1	9.0	8.5	3.3	352	Loop Used
5	38.9	69.5	40.9	9.0	3.6	3.3	353	Loop Used
Retrofit South								
1	32.8	31.9	23.1	12.2	11.1	2.0	127	Loop not used-does not meet wind criteria
2	46.6	39.6	22.4	13.9	8.9	2.9	110	Loop not used-does not meet wind criteria
3	37.9	33.2	29.2	14.5	7.6	4.3	196	Loop not used-does not meet wind criteria
4	31.5	40.5	17.6	16.2	5.9	1.8	330	Loop Used
5	16.2	42.1	30.2	11.6	5.6	4.2	334	Loop Used
6	51.6	44.4	27.6	12.3	5.1	4.0	89	Loop not used-does not meet wind criteria
7	26.2	35.1	13.5	11.2	15.7	2.2	69	Loop Used
8	64.0	42.7	30.9	14.8	9.3	3.2	12	Loop Used
9	22.7	38.6	15.4	16.2	17.1	4.5	296	Loop Used
10	15.7	37.2	28.3	14.2	11.4	4.6	321	Loop Used
11	30.0	38.9	29.5	10.0	4.7	4.3	324	Loop Used
12	20.7	29.8	23.5	15.5	15.8	2.4	89	Loop not used-does not meet wind criteria
13	20.4	43.8	41.2	15.9	13.9	4.2	348	Loop Used
14	50.7	37.2	27.3	12.1	5.9	4.1	27	Loop Used
15	17.3	41.2	30.3	9.0	6.8	3.3	322	Loop Used
16	15.2	16.0	12.8	16.4	5.1	2.6	325	Loop Used
17	19.8	41.2	28.1	8.4	5.9	4.8	318	Loop Used
18	15.7	40.5	32.6	7.5	6.2	2.9	351	Loop Used
19	30.9	41.3	35.0	14.0	5.7	4.0	24	Loop Used
20	71.3	33.8	33.3	11.4	11.2	3.1	88	Loop not used-does not meet wind criteria
21	23.3	40.0	38.2	11.7	9.2	4.2	101	Loop not used-does not meet wind criteria
22	22.4	33.3	21.3	11.4	8.5	2.3	324	Loop Used
23	36.2	28.2	12.6	11.0	12.1	2.4	346	Loop Used

Table B-8. Methane Concentrations (in ppmv) from the Biocover/Control Area Vertical Survey

Loop	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Wind Speed (m/s)	Wind direction from North (deg)	Comments
1	32.1	43.7	64.3	45.6	45.6	0.8	326	Loop used for Control
2	37.8	40.4	58.8	55.0	48.0	1.0	51	Loop used for Biocover
3	28.6	46.6	97.1	18.6	12.3	1.2	23	Loop used for Biocover
4	15.7	26.9	42.6	12.2	13.0	1.1	2	Loop used for Biocover
5	8.39	25.8	28.8	19.9	10.9	1.4	48	Loop used for Biocover
6	16.5	67.3	50.5	34.0	10.8	1.7	15	Loop not used-does not meet wind criteria
7	50.0	37.1	46.5	28.2	24.6	1.0	340	Loop not used-does not meet wind criteria
8	53.0	33.3	39.2	23.6	17.8	1.5	344	Loop not used-does not meet wind criteria
9	39.1	29.6	70.1	28.6	35.2	1.3	15	Loop not used-does not meet wind criteria
10	15.3	43.1	56.4	29.3	28.4	0.5	151	Loop used for Biocover
11	17.8	50.5	46.6	27.1	17.2	0.6	233	Loop used for Control
12	13.6	33.0	38.8	40.9	23.9	0.8	84	Loop used for Biocover
13	31.3	38.5	35.4	30.4	18.5	0.4	54	Loop used for Biocover
14	21.0	42.2	52.7	34.9	21.2	0.8	74	Loop used for Biocover
15	33.0	32.9	56.6	23.2	20.7	1.1	31	Loop used for Biocover
16	19.5	30.3	50.1	21.2	19.0	1.4	4	Loop not used-does not meet wind criteria
17	22.8	32.4	46.9	24.0	21.3	1.3	230	Loop used for Control
18	20.8	26.4	47.9	35.2	15.6	0.7	58	Loop used for Biocover
19	23.7	39.6	38.6	27.0	12.2	1.4	58	Loop used for Biocover
20	15.4	29.5	36.3	18.4	19.7	1.2	113	Loop used for Biocover
21	10.5	23.2	33.0	21.4	20.3	1.0	208	Loop used for Control
22	15.8	41.3	61.5	28.5	19.2	1.3	36	Loop used for Biocover
23	9.40	26.3	43.7	16.2	11.7	1.5	33	Loop used for Biocover
24	13.9	24.4	36.3	22.4	16.9	1.0	106	Loop used for Biocover
25	17.7	32.3	44.4	28.6	19.5	0.9	65	Loop used for Biocover
26	19.9	37.0	37.0	21.6	22.7	0.6	66	Loop used for Biocover

Loop	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Wind Speed (m/s)	Wind direction from North (deg)	Comments
27	18.1	54.1	49.8	32.3	30.0	0.7	58	Loop used for Biocover
28	28.0	50.1	38.6	32.8	29.2	0.9	77	Loop used for Biocover
29	28.7	47.1	39.0	29.5	28.2	1.2	6	Loop not used-does not meet wind criteria
30	50.0	73.7	68.0	47.0	47.9	1.3	20	Loop not used-does not meet wind criteria
31	53.0	78.8	55.7	52.4	41.1	1.0	357	Loop not used-does not meet wind criteria
32	39.1	78.6	71.3	40.3	39.4	1.9	85	Loop not used-does not meet wind criteria
33	36.7	74.4	83.2	48.3	39.5	2.3	29	Loop not used-does not meet wind criteria
34	11.1	61.2	55.1	20.3	17.2	1.3	147	Loop not used-does not meet wind criteria
35	14.9	35.4	43.2	30.6	25.9	2.4	56	Loop not used-does not meet wind criteria
36	15.1	18.1	23.8	7.53	7.75	4.8	64	Loop not used-does not meet wind criteria
37	21.6	14.1	14.5	8.73	6.76	3.1	105	Loop used for Biocover
38	7.95	14.7	20.7	8.67	5.96	2.9	77	Loop used for Biocover
39	9.46	18.8	33.8	9.27	6.90	3.7	58	Loop used for Biocover
40	7.93	15.9	61.7	19.4	20.4	1.6	35	Loop used for Biocover
41	19.0	47.1	35.3	14.2	6.03	4.1	44	Loop used for Biocover
42	14.9	35.3	31.1	22.9	33.4	1.6	355	Loop not used-does not meet wind criteria
43	26.9	35.7	31.5	24.7	21.0	2.9	355	Loop not used-does not meet wind criteria
44	32.6	18.6	25.2	25.7	15.7	2.5	344	Loop not used-does not meet wind criteria
45	7.71	38.6	43.2	27.1	27.0	3.2	356	Loop not used-does not meet wind criteria
46	25.2	58.3	23.9	16.1	6.85	4.0	66	Loop used for Biocover
47	11.3	17.6	22.6	14.9	7.15	3.8	76	Loop used for Biocover
48	24.4	44.4	39.4	25.5	17.0	2.9	352	Loop not used-does not meet wind criteria
49	40.0	35.6	51.0	27.8	7.92	3.3	363	Loop not used-does not meet wind criteria
50	16.9	24.2	39.0	16.2	17.8	4.1	37	Loop used for Biocover
51	19.1	20.0	18.8	10.6	9.65	5.1	76	Loop used for Biocover
52	16.2	17.6	19.3	8.96	4.84	5.2	83	Loop used for Biocover

Loop	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Wind Speed (m/s)	Wind direction from North (deg)	Comments
53	15.7	19.3	25.2	9.90	15.4	3.7	79	Loop used for Biocover
54	25.3	27.6	24.0	12.4	12.4	3.8	60	Loop used for Biocover
55	14.8	38.4	52.4	34.8	17.5	3.0	20	Loop not used-does not meet wind criteria
56	19.3	21.1	26.5	11.3	8.84	4.4	67	Loop used for Biocover
57	16.6	17.4	16.6	10.9	5.72	3.2	86	Loop used for Biocover
58	32.7	24.3	29.5	15.2	9.83	3.0	107	Loop used for Biocover
59	13.8	27.3	27.3	11.0	10.8	4.0	49	Loop used for Biocover

Table B-9. Methane, Ammonia and VOC Concentrations (in ppmv) Measured on Mirror 1 of the Biocover Area

Biocover				Concentration (ppmv)			
Mirror 1							
Loop	Methane	TFM*	CFM*	Ethanol	MTBE*	Ammonia	Ethylene
1	51	0.0057		0.104		0.012	
2	54					0.0068	
3	41					0.023	
4	38					0.028	
5	42		0.035			0.026	
6	32		0.028			0.031	
7	38		0.031			0.021	0.0077
8	28					0.016	
9	16				0.0059		
	Avg=38					.021	

*TFM= Trichlorofluoromethane

*CFM= Chlorodifluoromethane

*MTBE= methyl tert-butyl ether

Table B-10. Methane Concentration (in ppmv) found at the Compost Downwind Area

Loop	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Wind Direction
1	5.8	5.1	5.8	4.2	183
2	5.8	5.1	5.3	5.5	135
3	5.3	5.3	6.0	4.3	144
4	5.2	5.3	6.8	5.6	166
5	6.4	5.4	6.2	4.6	208

Table B-11. Methane Concentrations (in ppmv) found at the Compost Upwind Area

Loop	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Wind Direction
1	10	13	13	12	11	322
2	7.3	11	9.5	10	10	218
3	10	10	9.3	10	10	280
4	7.7	9.1	8.4	8.6	8.8	297
5	8.7	10	10	10	11	259
6	10	11	11	13	13	274
7	8.5	15	15	15	16	235
8	19	20	19	20	22	224
9	13	28	27	29	28	239
10	28	30	27	28	26	225
11	22	26	23	24	24	234
12	12	23	21	22	21	225
13	5.4	6.1	5.9	4.7	6.7	143
14	5.4	7.2	6.4	5.5	8.3	132
15	5.7	6.3	6.4	4.8	6.9	104
16	6.1	7.5	7.4	5.7	7.1	87
17	6.0	7.1	6.0	5.4	5.4	168
18	6.0	8.0	5.7	6.1	9.0	290